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DECOMPOSITION OF ROCKS IN BRAZIL.

UNDER the above title Dr. J. C. Branner[1] has recently brought together an extensive series of observations scattered through the literature relating to Brazil, with many original notes of his own bearing on the subject of rock decay in that country and the causes of the exceptional character and depth attributed to it by most writers. While appreciating fully the value and interest of the facts collected in the said paper, the present writer is somewhat inclined to question the hypothesis that furnished the motive for the collection, that is to say, the hypothesis that rock decay in Brazil is of an exceptional character requiring for its explanation the operation of special causes. The subject is one in regard to which he has felt great diffidence in formulating an opinion, even for his own private use, from his lack of familiarity with other regions of like petrographical and geological structure but situated under different climatic conditions, with which alone the comparison can properly be made. As it is probable, however, that in this respect he is in the same boat with many of the writers whose observations are relied upon for establishing the major premise in the case, he ventures to present some of his own observations on certain aspects of the subject.

Professor Pumpelly treating of the secular decay of rocks[2] has well remarked that "The depths of this decay, other things

[1] Bull. Geol. Soc. of Am., Vol. VII, p. 256.

[2] Bull. Geol. Soc. of Am., Vol. II, p. 210.

being equal, is determined by lapse of time, by the permeability and by the solubility of the constituents rather than by its hardness." If under permeability we include such features of geological structure as fissibility, jointing, etc., which facilitate the access of water to the interior of rock masses independent of the structure of the rocks *per se*, and the position of the planes of such geological structure with reference to the source of water supply, the law as above stated may be taken as covering the entire question to be considered.

Of the authors who have treated of rock decay in Brazil, the two whose opinions are entitled to the most weight, Agassiz and Hartt, believed (at least at the time of writing) in the general glaciation of the country by which the element of time in the formation of the present coating of decomposition products would be materially reduced. If, as Branner has recently shown to be probable,[1] these authors afterward modified their views regarding glaciation, they would doubtless have expressed themselves very differently on the subject of rock decay. At all events, for those who, like Branner and the writer, do not believe in the glaciation of Brazil, the time element is practically unlimited and the question becomes one as to whether or not the other factors of permeability and solubility are sufficient to account for the phenomena observed.

That the decomposition of Brazilian rocks, particularly those of the crystalline and semicrystalline groups, is both widespread and profound is abundantly proven by the numerous examples cited in Branner's paper. It is even probable that the cases cited fall far short of the extremes that may be found when the country is more fully explored. Thus far, however, no authentic Brazilian example in gneiss equals that of the bed in the Hoosic Tunnel decayed to a depth of 230 feet below the outcrop (in a glaciated region be it noted) cited by Hunt,[2] or in granite that of the Cornish example rotten to the depth of 600 feet, cited by Geikie.[3] According to the latter authority, the kaolinization of

[1] Jour. of Geol., Vol. I, p. 753.

[2] Am. Jour. Sci., 3d ser., Vol. XXVI, p. 198.

[3] Text-Book of Geol., 2d ed., p. 322.

the Cornish granites frequently extends to a depth of 50 or 60 feet, which represents fairly well the generality of cases of decay of this type of rock in Brazil.

Although not clearly expressed, it is evident that most writers in treating of the region about Rio de Janeiro, to which most of the observations on rock decay in Brazil refer, have assumed that the massive types of granitoid gneiss and, to a subordinate extent, of true granite, which are about the only rocks seen in a sound condition, represent the generality of rock in the region, and that the great masses of decomposed rock seen belong necessarily to these resistant types. It seems also to have been assumed that the accidents of relief giving abrupt differences of level of hundreds, or even thousands, of feet are mainly due to extraordinary erosion preceded by decay to extraordinary depths. The clearest expression of this view is found in the long-shot explanation by Agassiz of the so-called organpipe peaks (see Fig. 4 of Branner's paper) as hard vertical strata of gneiss left standing by the gradual decay of softer intervening strata. Up to the present time the peaks in question have never been examined close at hand by a competent geologist and as both gneiss and granite occur prominently in the range it is doubtful which of these two types of rock forms the peaks, or what may occur in the intervals between them.

It is certain, however, that the apparent uniformity of the massive types of rocks is due to their great resistance to decay in virtue of which they form the greater part of the hills which generally present bare rocky bosses at the summit while the flanks are heavily wooded. In the flanks between these hills basic eruptives, principally diabases, frequently appear which, though equally massive, seem to be more susceptible to decay although their apparent limitation to the lower levels may in part be due to their emergence along lines of fracture and of consequent weakness and of susceptibility to decay. Much more frequent in the lower grounds and in the hills of deeply decomposed material are schistose gneisses which from their lack of homogeneity and their position with the planes of fissibility

standing nearly vertically are highly permeable and so subject to decay that they are rarely found in a sound condition and have generally been overlooked. In the absence of a detailed geological study it is impossible to estimate, even approximately, the relative areas occupied by the comparatively impermeable granitoid gneisses and granites and these highly permeable schistose gneisses, but presumably the areas formerly occupied by the latter were at least equal to those of the former.

As regards the origin of the present abrupt topographical features the importance of faulting in their formation has scarcely been hinted at, and yet, as an examination of the excellent figures accompanying the paper cited will show, it seems to afford the most natural explanation of many of these features. Admitting that faulting on an extensive scale has taken place in the region, it will be readily seen that the downthrow side of a fault will be in very different conditions as regards the agencies of decomposition (even when the same type of rock is concerned) from the upthrow side. The latter receives only the water that actually falls upon it from the clouds and the time for infiltration (until a covering of decomposed material is formed that serves to retain a portion of the water) is practically limited by the duration of the rain. Under these circumstances the granitoid gneisses and granites of Rio de Janeiro and of the Serra do Mar region generally, are so nearly impermeable that the tops of the bosses are almost always bare and waste mainly by the process of exfoliation. On the slopes where the rock may be more shattered and where talus accumulates the meteoric waters have a greater scope for action particularly after vegetation has established itself on the decomposition crust that is gradually formed which, serving as a saturated sponge, greatly prolongs the time of infiltration of the surface waters to the underlying rocks. The downthrust side of a fault in addition to its own proper share of meteoric waters receives also a large part of the drainage of the upthrust portion not only during the downpour of rain but for some time after and the access of the water to the interior of the rock mass will be

facilitated by the fault plane and by any secondary shattering that may attend it. It may thus happen that in the distance of a few feet the same rock may be found almost perfectly sound and profoundly decomposed, and in cases of apparently abnormal decomposition the local conditions should be carefully studied before special causes (which will often be found to have respected adjacent rock masses) are called into play.[1]

Of the greater part of the examples that have been cited as showing the extraordinary extent of rock decay in Brazil no details regarding petrographic character and topographical position have, or can be, given from which an opinion can be formed as to whether or not the decay is normal or abnormal in character. The two exceptions are the cases of the Pedregulho reservoir in Rio de Janeiro and of the new shafts of the Morro Velho mine in Minas Geraes for both of which the figures are definite and the conditions are such that the decay observed may be considered as about normal for the kinds of rocks concerned.

[1] The subject of faulting has received very little attention in the study of Brazilian geology, but it is becoming apparent that many of the topographical features are due to faults and their determinative effects upon erosion rather than to erosion pure and simple as generally assumed. The evidences of faulting are most apparent in the regions of horizontal sedimentaries and bedded eruptives of the southern part of the country, but there are reasons for believing that they will also be found, perhaps on an equal scale, when detailed studies are made of the more ancient regions of eastern and central Brazil and of the more modern ones of the northern part of the country. For the latter region the possibility of faulting was suggested, rather too obscurely, as it appears, in a brief résumé of what was known of the Cretaceous in Brazil prepared by the present writer to accompany the monograph of Dr. C. A. White on the fossils of that age (Archivos do Museu Nacional do Rio de Janeiro, Vol. VII). The paragraph in which attention was called to the comparatively low level of the fossiliferous coastal basins as compared with the beds of the interior referred to the same age but with, so far as known, a different fauna, suggestive of a possible rise of the land occurring between the two faunas, has been strangely misapprehended by Dr. Branner who characterizes it as a hypsometric classification of formations. (The Cretaceous and Tertiary Geology of the Sergipe-Alagôas basin of Brazil, Trans. Am. Phil. Soc., Vol. XVI, 1889, p. 410.) As he unites the two faunas on no better ground than the attempted refutal of the supposed low level of the coastal basins, the epithet may perhaps with greater justice be applied to his own reasoning. The refutal in question is contained in the statement that the Cretaceous beds extend to within 150 meters of the top of the Serra de Itabaiana which, according to Mouchez,

The Pedregulho hill is an isolated elevation surrounded by tidal swamps and old beach deposits, of the type so well described by the Brazilians as a half orange. It thus presents the most favorable disposition for the preservation of the decomposed material except for the inevitable waste from rain washing and wind action, and (at least since the present topographical conditions were established) it has received no material from adjacent higher lands and only its own proper amount of atmospheric waters. The cutting away of the top of the hill for the reservoir foundation exposed the upturned edges of a highly schistose gneiss in which the different layers, rarely more than a few centimeters thick, vary greatly in the relative proportions of quartz, feldspar and mica (biotite) and consequently in permeability and susceptibility to decay. On the whole, however, it may be said that the rock represents the most susceptible type of the neighborhood and is in the most favorable conditions for rapid decay. At the depth of sixty-five feet from the original summit of the hill the rock was considered sufficiently firm to build upon though it was nowhere perfectly sound and many of the layers were completely earthy, partial decomposition evidently extended much deeper, and it may even be presumed that in some of the layers it may have extended nearly or quite to drainage level, that is to say to near the base of the hill 225 feet below the original summit.

In the case of the Morro Velho mine the rock concerned is a hard bluish clay slate, but without well defined slaty cleavage, standing nearly vertically. It is very uniform in character and

rises to an elevation of 700 to 800 meters above tide. Mouchez's figures are presumably a sailor's estimate at long range and are not in accord with two aneroid determinations which gave 520 and 608 meters. The section and detailed description of the mountain given in the same paper represent, in perfect accord with my own observations in the region, the Cretaceous beds as terminating at some distance from the base of the mountain, at an elevation of about one-third of its height and only slightly greater than that of the Tertiary which is stated to be about 200 feet. So far as the present evidence goes, therefore, the original estimate of about 100 meters as the maximum elevation of the coastal beds may still stand. As at no great distance the base of a very extensive and apparently very different horizontal series of secondary beds is at an elevation of about 300 meters, faulting is strongly suggested.

texture throughout a considerable thickness and, so far as can be judged from a simple inspection, should be one of the least susceptible to decay of the series of metamorphic schists to which it belongs. The notes given by Branner refer to two sets of shafts which should be carefully discriminated. The first were sunk at the bottom of a gorge, possibly a fault line, and thus were almost wholly below drainage level. The term "jointy" applied in the mine report to the first dozen fathoms would hardly be used by miners for a decomposed condition of the rock so that the depth of timbering (126 feet) is probably a measure of the depth to which the rock was shattered, perhaps through faulting, rather than decay. The new shafts, to which the information given by the present superintendent refers, are so situated that the depth at which "blasting rock" was found affords a good measure of the normal decay of this class of rocks above drainage level. They are on the side of a campo-covered ridge with a slope of 20° to 30° to the nearest stream some 300 feet below the mouth of the shafts. Decomposition here, though profound (155 feet), is still far above drainage level and probably under the same circumstances the more permeable rocks of the same series (especially those in which rapid alternations of layers of different composition and texture occur) would be found decomposed to a much greater depth. Thus in the adjoining Faria mine the depth cited (164 feet) probably refers to the depth of working and not to that of decay which under the circumstances of the mine and of its rock may be very much greater. On the other hand the soft bed intercalated in hard rock reported at Morro Velho at a depth of 755 feet could hardly have been a case of normal decay. So also the soft (friable) rock reported in the Cocaes (300 feet) and Gongo Socco (375 feet) mines probably do not represent decomposition as it is very doubtful if the rock of these mines (itabirite) was ever in a compact condition.

In traveling through the mining districts of Minas Geraes, which are mainly in campo, one gets the impression that rock decomposition is even more profound than in the forested coastal

region. In part the predominant rocks are of a totally different character representing in general terms the so-called crystalline schists with the exclusion of the true gneisses, and taken as a whole, it may perhaps be assumed that they are more susceptible to decay than the rocks of the coastal region in which gneiss and granite predominate. The comparison to be a fair one should be made between campo and forest region constituted by rocks of, as nearly as may be, the same character. The only elements for such a comparison are the superficial observations from the car window in traveling over the Central Railroad. In the long stretch of line in the forested region from Rio de Janeiro over the Serra do Mar and along the Parahyba and Parahybuna valleys to the crest of the Mantiqueira range one seldom fails to see sound rock, gneiss or granite or both, in the bottom (and often in the entire side) of cuttings that exceed a moderate depth. After passing the crest of the Mantiqueira and entering the campo region of Barbarcena sound rock is the exception rather than the rule in the cuttings though these continue as numerous and deep as in the other section and are also, for the most part, in gneiss and granite. The appearance, possibly deceptive, is that decomposition is even more profound in the campo than in the forest region. One plausible explanation for this difference is topographical, since in the forest region the road mainly follows the valleys and is consequently near drainage level whereas in the campo region it is more independent of the streams and is in general considerably above that level The rocks also, although of the gneiss and granite type, are apparently more acid in composition with a greater abundance of free quartz and of potash mica while magnesia, mica and amphibole are the predominant bisilicates in the rocks of the forest region. There are many indications that this difference in composition is accompanied by a greater susceptibility to decay although exact observations on this point have not been recorded. The differences noted in topographical structure and in rock composition may account for the apparently greater decay in the campo region and in that case the decay in the two regions

contrasted may be taken as approximately equal. So far as the present evidence goes, however, it is to the effect that in the districts of highly inclined crystalline and metamorphic schists of the states of Minas Geraes and Rio de Janeiro profound rock decomposition is not a concomitant of the present distribution of forests.

An interesting feature in the decay of some types of granite is that a considerable portion of the feldspar resists decomposition almost as well as the quartz and the rock disintegrates into a coarse gravel with comparatively little earthy, or completely decomposed, elements. This was first noticed on any considerable scale in a relatively arid region along the São Francisco River and was thought to be a case of arrested decay due to deficient rainfall. It has since been found, however, to be independent of climate as in the same region some rocks may be found decayed in this way while others in the immediate neighborhood are completely decomposed. Curiously enough the soils in which only a portion of the silicate elements of the original rock have become earthy are considered very good and in São Paulo these "rock-salt" (*salmarão*) soils are favorite ones with coffee planters.

With the rocks thus far considered, that is to say, the crystalline and metamorphic schists and their associated granites, decomposition, although very variable, is undoubtedly extensive and, very probably, is in many points much more profound than in any of those at which accurate measurements, or estimates, have been made. In general, however, it is to be measured by scores and not by hundreds of feet and, so far as the present evidence goes, the differences to be noted from one point to another are rather to be attributed to original differences in susceptibility, in permeability (due to original or superinduced textural and structural features), in the position of the rock masses in their exposition to the agencies of decay or with reference to the drainage level, rather than to climatic or biologic causes. With reference to this last point it would be interesting to compare the regions above considered with such a one as that mentioned by Allen[1] in the semi-arid region of Central Bahia,

[1] HARTT, Geol. and Phys. Geog. of Brazil, p. 314.

where gneiss and granite appear in a vast and almost level plain with only a slight covering of decomposed material. For this, however, data is lacking and it is impossible to say how much of the characteristics of this region is to be attributed to climate alone.

Turning our attention now to other groups of rocks, some of these are found to have resisted remarkably well the "torrents of hot water falling for ages in succession upon hot stones" in the phrase of Professor Agassiz. (The temperature of 140° to 150° F. recorded by Caldcleugh for rain water running over exposed rock surfaces would seem to require confirmation.) In crystalline rocks in which the inalterable quartz is replaced by silicates susceptible of alteration, such as nepheline and sodalite, much more rapid and profound decomposition might be expected than in the granites and gneisses. On the contrary, however, these, though decayed in places, are generally found in a sound condition at or near the surface. With many of these rocks a peculiar crust of kaolin and limonite forms on the surface of the decayed portion which serves as a very efficient protection for the inner portion of the masses. The more feldspathic types (augite-syenite) seem, contrary to what might be expected, to be more susceptible to decay than those rich in the silicates above named. The character of the bisilicate element also seems to be of considerable importance as in a recent excursion to the peak of Itatiaia no difficulty was experienced in obtaining satisfactory specimens from the exposed blocks, or bosses, of nepheline-syenite, augite-syenite, phonolite and even tufas, whereas a very extensive exposure of mica-syenite was searched in vain for a perfectly sound sample of the rock. In this, as in some other cases, it looks as if some of the elements set free by the decay of the rock itself might be more potent for continued decomposition than those derived from the atmosphere. The general soundness, though many exceptions occur, of the porphyritic (phonolitic) types of these rocks is especially noticeable as it is understood that in many temperate regions this type, though presumed to be geologically newer than in Brazil, is considered to be particularly susceptible to alteration.

An opportunity for observing the phenomena of decomposition under substantially the same climatic and biologic conditions but with reference to a totally different series of rocks is afforded by the recent notable extension of coffee culture in the interior of the state of São Paulo with the accompanying extension of the railway system. No critical study of this region has as yet been made and, as in nearly all that precedes, the observations (whether those of the writer or of others) must be taken as railroad geology and, as such, subject to future revision.

The region in question lies immediately to the west of that above considered and in so nearly the same conditions as regards latitude, elevation, rainfall, and forest distribution that the differences may be considered as unimportant for the present discussion. The features of geological and topographical structure and of the character of the rocks are however widely different. The dominant geological and topographical features are given by soft shales and sandstones of late palæozoic (Permian?) and early secondary (Triassic?) age which are practically horizontal though much disturbed by faults and dykes and sills of basic eruptives. The latter belong exclusively to the group of augite-porphyrites as defined by Rosenbusch and represent all the varied phases of that group. According to all the indications at present known the region has stood as dry land ever since early secondary times. Much of it is in campo but considerable forest tracts occur. No direct relation can be traced between the distribution of forest and campo and the character of the underlying rocks, though in general it may be said that campo predominates over forest in the areas in which the sedimentaries give character to the surface soil, the contrary being the case where the eruptives come to the surface.

In this region the evidences of profound decomposition are far less prominent than in the mountainous districts above referred to. The railroad cuttings are not deep, seldom exceeding a half dozen meters, but they rarely fail to show some rock in a comparatively sound condition which frequently extends to within a meter or less of the surface. The sedimentary rocks

are almost invariably quite soft even where they show no signs of decay, and go to pieces by a kind of slacking process when broken up and exposed to the air, though they may have required blasting in the original opening of the cuttings. The eruptive rocks vary greatly in their resistance to decay. The porphyritic types, especially when they are amygdaloidal, are often in a state of incipient, or complete, decomposition to a depth quite as great, or perhaps even greater, than that noted in the granite and gneiss regions, while the types approaching diabase in character are often sound, or only broken up into bowlders of decomposition, quite to the surface. As the decay of these basic rocks affords the favorite coffee soil, the famous *terra rexa*, the forested tracks where they occur have been very generally cleared and planted, and the coffee orchards (where the underlying rock is diabasic) seldom fail to show loose stones and frequently continuous outcrops of rock at the surface. Many of these orchards are on almost level tracts, so that the comparative thinness of the capping of decomposed rock cannot be attributed to excessive washing. In short, considering the length of time that this region has stood as dry land and the favorable topographical disposition for the preservation of the products of decay, the average amount of rock decomposition may be said to be surprisingly small rather than surprisingly great, and where it is profound, the cause must be sought in the susceptibility of the rocks themselves and not in climatic or biologic conditions.[1]

ORVILLE A. DERBY.

[1] In treating of the organic agencies affecting the soil, Dr. Branner notes that the action of earth worms is much less important in Brazil than in temperate regions. The same remark has been made by Mr. H. H. Smith, a very acute and accurate geological and biological observer. My own experience is so far in accord with these observations that only once has decided evidence of the action of earth worms been noticed. This case however was so striking that the absence of other observations may perhaps be attributed rather to lack of attention to the subject, or of favorable conditions for observing the action of these humble manipulators of the soil, and not to their absence. An old pasture that had been wet by a shower after a burning that had completely bared the surface, was so thickly covered with the vermicular heaps thrown up by earth worms that over a space of several acres it was almost impossible to put down the hand without touching one or more of them.

ITALIAN PETROLOGICAL SKETCHES.

I. THE BOLSENA REGION.

Introduction.—The number and easy accessibility of its volcanoes render Italy an enticing field for the geologist. The peculiar characters of their eruptive rocks, which are rich in potash, and in which leucite is a most common mineral, render them of special interest to the petrologist. It would seem, however, judging from a quite extensive survey of the literature, that the country has been rather neglected in recent years by petrologists; since, except for a comparatively small number of modern papers describing limited districts, we must turn for many of our descriptions to the writers of more than a quarter of a century ago. Few attempts also have been made to correlate the facts in our possession for the purpose of determining the general petrological characters of the Italian province.

In the autumn of 1894 the writer had the opportunity to pay brief visits to most of the Italian mainland volcanoes and make collections of their representative rocks. A study of the specimens collected revealed so many new and interesting features that it was decided to publish a series of short papers on various Italian volcanoes. In these the separate rocks will be described, and some general conclusions which have been drawn from their study will be presented in a final paper. The work of the modern school of Italian petrographers will be used and quoted extensively, since it is comparatively little known to the outside world. As the time devoted to each volcano was all too brief these papers must be sketches merely, and will be predominantly petrological in character.

I. THE BOLSENA REGION.

Bibliography.—The work of the early geologists—such as Breislak, Brocchi, Pareto and Pilla—need not detain us, as they

are of little interest in the present connection. We may note, however, that Pareto in 1844 pointed out three centers of activity, Latera, Torre Alfina and Montefiascone, around lake Bolsena.

Vom Rath[1] in 1868 gave a detailed description of the region. His paper is largely topographical, with some descriptions of the tuff and lava beds and a couple of analyses. He does not consider the lake as the remains of one large crater, but thinks that it is due to a sinking of the surface (*Einsenkung*), and that the circle of hills was produced by eruptions at different points around this tract.

Stoppani[2] in 1873 gives a description of the volcano, in the course of which he expresses his belief that the lake is in reality the site of a vast crater, slightly enlarged by erosion; at the same time recognizing the existence of parasitic cones, of which he gives Monte Rado near Bagnorea as an example.

In 1888 Verri[3] published a geological sketch of the region, the rocks collected by him being handed over to Ricciardi for chemical analysis and to Klein for petrographical description. After a brief historical and topographical description he discusses the order and epoch of the eruptions, and then describes in detail the various eruptive centers around the lake. The origin of this he holds to be that given by vom Rath. He considers that the tuffs of the region were erupted in the condition of mud —a conclusion, it may be added, which is strongly combated by other Italian geologists.

Klein's[4] article is composed of petrographical descriptions of Verri's specimens, which include most of the prominent rocks of the region. Though the descriptions are short and concise, they give a very good idea of the rocks; and I am happy to say that my own studies of specimens from the same localities substantiate Klein's descriptions in almost all points. The paper

[1] VOM RATH, Zeit. d. d. geol. Gesell., XX, 265–294, 1868.

[2] STOPPANI, Corso di Geologia, Milano, 1873, III, 376, 386.

[3] VERRI, Boll. Soc. Geol. Ital., VII, 49–99, 1888.

[4] KLEIN, Neu. Jahrb., B. Bd., VI, 1–35, 1889.

also contains the complete set of Ricciardi's analyses, which were published by him elsewhere.[1]

In the same year Moderni[2] published a short paper on the trachyte and tuff of Rispampani near Toscanella, which lies to the south of Lake Bolsena. He states that the trachyte forms a dome resting on Eocene beds. The trachytic tuff is remarkable for its radiating columnar structure, and resembles a lava in external characters.

In an important paper on the extinct volcanoes of the northern Apennines de Stefani[3] takes Lake Bolsena as the type of the crater-lake eruptions and gives a detailed description on the basis of his own observations. He differs from Verri in several points, notably in regard to the genesis of the lake, which he regards as a large central crater, at the same time recognizing the existence of flank eruptions, and comparing the volcano to those of the Hawaiian Islands. The interesting general conclusions regarding the Italian volcanoes which he gives at the end of his paper will be noticed elsewhere.

The last writer to treat of the region is Bucca[4] who gives short petrographical descriptions of a number of the leucite rocks.

Topography.—The center of the region is Lake Bolsena, which lies northwest of Rome and southwest of Orvieto, in Lat. 42° 35′ and Long. 12° 20′ E. Its shape is quite regularly elliptical, the major axis running north and south. Its dimensions are 13 by 10 kilometers, with a surface area of about 112 square kilometers, being thus the largest crater-lake in Italy, and one of the largest in the world. The surface of the lake is 305 meters above sea level, and the greatest observed depth is 140 meters. The two small islands of Bisentina and Martana rise a few meters above the surface in the southern and southwestern parts of the lake. They are composed chiefly of tuff and seem to be the remains of small volcanic cones.

[1] RICCIARDI, Gazz. Chim. Ital., Palermo, 1888.

[2] MODERNI, Boll. Com. Geol. Ital., X, 19–25, 1889.

[3] DE STEFANI, Boll. Soc. Geol. Ital., X, 499–537, 1891.

[4] BUCCA, Rivista Min. e Crist., 18–30, 1893.

Surrounding the lake and sloping steeply down to its waters (leaving only a narrow shore margin), is a girdle of hills whose most elevated points on the north are 600 to 680 meters above sea level, and hence 300 to 375 above the surface of the lake. Towards the south they diminish in height, a feature which this crater possesses in common with others of Italy.

These hills are made up of volcanic material, chiefly leucitic lavas and tuffs, though to the north of the lake considerable "trachyte" is found. In places fine sections of superposed tuffs and lava streams are exposed, and in the latter a columnar structure is sometimes very well developed. From the crest encircling the lake the surface slopes gradually down on all sides, till the volcanic ejectamenta thin out in tuffs resting on the Sub-Apennine pliocene marine marls.

The whole district occupied by volcanic material thus forms a low lenticular mass (with the lake in a hollow at the center), whose outer sides slope at angles of 12° to 15°. Its diameter is about 40^{km} and its total area some 1300 square kilometers, as has been estimated by Stoppani and Verri. Erosion of the soft tuffs has cut up the surface to a great extent, producing characteristic radiating ravines, which de Stefani compares with our western canyons in miniature, and forming isolated buttes such as those on which the towns of Orvieto and Civita di Bagnorea are so picturesquely situated.

Lying immediately to the west of Lake Bolsena is another depression, or rather plain surrounded by a girdle of hills, also of least height to the south, its circle impinging on that of the Bolsena Crater. This crater, which is known as the Latéra Crater, is smaller than that of Lake Bolsena, having a diameter of about 7^{km}. The small Lake Mezzano, which occupies part of the area, preserves well the form of a crater, and may be looked upon as the site of the last eruption of the Latéra volcano. This seems, from the descriptions, to be a distinct eruptive center, though nothing is said by any of the writers mentioning it as to its age relative to that of the Bolsena volcano. It would seem, however, to be the more recent, since the original crateriform

character of both the exterior Latéra and interior Mezzano craters are better preserved than in the case of Bolsena; and also because it is, according to Stoppani, at present in a solfataric state.[1] The lavas of Latéra are entirely leucitic, so far as is known, no trachytes having yet been found at this center.

To the north of the Bolsena Region lie a number of small isolated volcano vents, such as the "trachytic" Monte Amiata and the basaltic hill of Radicofani. To the east are the Tertiary deposits flanking the main line of the Apennines, and to the south lies the closely similar volcanic Viterbo Region, which will form the subject of the next paper.

As to the character of the eruptions little need be said here, though I may insert de Stefani's summing up of the subject. He says:[2] "In conclusion we can hold that the volcano, submarine in the beginning, became later subaërial and erupted in the midst of a low and swampy region like the Maremme (marshes) of the present day in the same country." He thinks that the latest eruptions of tuff were dry and probably fell on dry land.

Discussion of the origin of the lake must be deferred to another place, since the existence of such crater-lakes is a feature common to several of the regions to be described. We may note, however, that there are two prominent theories. One is that of vom Rath and Verri, who regard the lake as a sunken tract, the sinking being due to the ejection of material from various points which forms the hills surrounding it. The other is that held by Stoppani and de Stefani, who consider the lake as the volcanic center, the remains of a large crater which has been enlarged by explosions and the falling in of its walls; and from which was ejected the greater part of the volcanic material, small flank eruptions also adding to the mass of the volcano. I may remark, in anticipation, that the weight of evidence and analogy is in favor of the latter theory.

[1] As I did not visit this western part of the region I cannot say whether one crater circle cuts the other or not, and I can find no mention of this point in the literature.

[2] DE STEFANI, op. cit., 526. He notes that von Buch expressed the same view about 1810.

As to the period of the eruptions de Stefani points out that in certain places, especially in the northern part, volcanic products alternate with marine fossil-bearing strata of the late Pliocene; and we may assume that the main eruptions began in the Pliocene period. Both he and Stoppani also give reasons for thinking that the latest eruptions were contemporary with man and geologically very recent.[1]

PETROGRAPHY.

The petrography of many of the Italian volcanoes is involved in considerable confusion. This is especially true of the regions immediately around the great crater-lakes. We shall see that these large volcanoes erupted a great variety of lavas, while the smaller eruptive masses flanking this main line offer much less variety, each separate mass being largely composed of one definite type of rock. The Bolsena volcano is no exception to this rule, which de Stefani[2] has brought out very clearly.

The confusion results partly from the tendency which many of the types have, especially among the leucitic rocks, of grading into one another; and partly from the presence of peculiar non-leucitic rocks which do not fit exactly into any place in our scheme of classification, and whose naming is largely a subjective matter.

It has lately been pointed out by Brögger[3] and Pirsson[4] that at the present stage of the science we must recognize the quantitative chemical and mineralogical relations as well as the qualitative. Brögger[5] has also made an able plea for the recognition of transition groups, the importance of which in our classification he brings out very clearly. With Brögger's views on the subject I, like Pirsson, heartily concur; and his principles will be recognized in the classification of the rocks which we shall

[1] STOPPANI (p. 384) quotes Gualterio as arguing for the probability of the formation of the Bolsena volcano during the paleolithic period.

[2] DE STEFANI, op. cit., 550.

[3] W. C. BRÖGGER, Gest. d. Grorudit-Tinguait Serie, Kristiania, 92, 1894.

[4] L. V. PIRSSON, Am. J. Sci., L, 478, 1895.

[5] BRÖGGER, op. cit., 93, and Eruptionsfolge bei Predazzo, Krist., 1895.

examine. This will involve the proposal of some new names, but the baptismal rite will be indulged in as sparingly as may be.

For the present we must confine ourselves to the Bolsena volcano, and may say that two prominent types exist, the trachy-andesitic and the leucitic rocks. Even these two prominent types grade into one another to a slight extent, though they can as a rule be readily distinguished. In the following pages I shall describe my own specimens, turning to Klein and Bucca for descriptions of rocks which I was unable to collect. The tuffs and the metamorphosed ejected blocks will not be touched upon. Ricciardi's analyses cover the ground so completely that only one fresh analysis was made, of the important Bolsena "trachyte." Vom Rath's analyses and the best of Ricciardi's will be inserted later.

Vulsinite.—Vom Rath first called attention to the abnormal chemical character of the "trachyte" of Bolsena, though he speaks of it as containing no plagioclase, probably owing to the rarity of the multiple twinning. As will be seen from Klein's descriptions and my own, and from the analyses, the peculiar "trachytes" of the region are remarkable; mineralogically for their richness in plagioclase and the frequent occurrence of olivine as an essential constituent, and chemically for their low silica and high lime and magnesia. Therefore they are not trachytes proper, but correspond to the trachy-dolerites of Abich[1] and Hartung,[2] and to some of the andesitic-trachytes of Rosenbusch,[3] and we shall see that they may be regarded as effusive representatives of Brögger's abyssal monzonites. These olivine-free effusive rocks will be called by the name of *Vulsinite*,[4] from the Etruscan tribe, Vulsinii, formerly inhabiting this region. Those carrying olivine belong to a peculiar type which will be described in the next paper.

[1] ABICH, Nat. n. Zusammensetz. d. Vulk. Bild., p. 101, 1841.

[2] HARTUNG, Azoren, Leipsig, p. 92, 1860. Cf. MUGGE, Neu. Jahrb., Vol. II, p. 201, 1883.

[3] ROSENBUSCH, Mikr. Phys. Vol. II, p. 600, 1887.

[4] The name Bolsenite has already been used by H. O. Lang (Min. Pet. Mit., XIII, 143, 1892) for one of his purely chemical groups, which embraces certain leucitic rocks.

These rocks are not very abundant in the region, and seem to be more common in the northern part than elsewhere. In certain cases they belong to the earlier eruptions, prior to those of the leucitic rocks. Purely alkali feldspar-trachytes seem to be unknown about this center, unless Moderni's trachyte of Rispampani belongs here, a point which his brief description does not permit us to decide. The plagioclase end of the series is represented by the augite-andesite of Monte Rado, which is also olivine-bearing.

The only specimens of vulsinite in my possession were collected from a small eminence on the eastern shore of the lake, immediately to the north of the small town of Bolsena. The locality is mentioned by Verri and de Stefani, and the rock is the same as that described by Klein (p. 8), with whose descriptions my specimens agree very closely. It is probably identical also with the trachyte of vom Rath (p. 291), though Nassini's quarry, whence he obtained his specimen, does not seem to be known at present. The rock belongs, as we shall see, to one of the earliest outflows.

Megascopically it is fine-grained and compact, with marked cutaxitic structure. The greater part is light ash gray, but mottled with spots and streaks of dark gray and yellowish brown. The structure here seems to be due to a mingling of magmas of somewhat different composition. Many glassy phenocrysts of feldspar, as well as smaller ones of augite and a few of biotite, are to be seen. The specific gravity is 2.534 at 25° C.

The feldspar phenocrysts are both alkali feldspar and plagioclase, the former in the majority but the latter quite common. Twinning, according to the Carlsbad law is not rare in the orthoclase, and one very perfect example of a Baveno twin was seen. While twinning is the rule with the plagioclase, yet multiple lamellæ are not often seen, and some untwinned crystals occur. Zonal structure is not frequent. The polarization color furnishes the readiest method of distinguishing between the two feldspars, that of the plagioclase in my sections, which are about $0^{mm}.2$ thick, reaching the light straw yellow of the first order. The

difference in refractive index is also marked. Inclusions are not very abundant and are usually small spots of glass, with some augite, magnetite and apatite crystals. In the alkali feldspar phenocrysts inclusions of plagioclase of some size are occasionally seen, but the reverse was not noticed.

The examination of plagioclase phenocrysts in the slides was made with care and resulted in establishing the fact that they are anorthite. In a section cut approximately parallel to *c* (001) an optic axis emerges almost perpendicularly, and the angle of its extinction is 38° with the trace of the plane *b* (010). The alkali feldspar border (to be described presently), in this case extinguishes parallel to the same plane of the anorthite crystal. In another section cut parallel to *b* (010) the plane of the optic axes (determined by the emergence of an axis at the border of the field), formed an angle of —34° with the basal cleavage cracks, while the individuals of the Carlsbad twin extinguished at 29° and 30½° on each side of the twinning plane. The border around this crystal extinguished at an angle of 11° with the basal plane of the anorthite. This determination of the plagioclase as anorthite confirms Klein's observation of its basicity.

Apart from the composition of the plagioclase, the most interesting feature of the feldspars is brought out between crossed nicols. It is then seen that both alkali feldspar and anorthite phenocrysts are surrounded, almost without exception, by a border or mantle of alkali feldspar of late growth. This forms one individual around the phenocryst proper, as shown by the simultaneous extinction of the whole border. The outer edge is in general very irregular, ending with an uneven and often uncertain line against the groundmass; though here and there there has been an attempt to fill out the crystal form, resulting in quite sharply defined straight edges.

The mutual extinctions prove that the mantle is orientated like the nuclear crystal, and if the inner orthoclase crystal be twinned the twinning is continued uninterruptedly in the outer mantle. This is also true to some extent of the Carlsbad twin-

ning of the anorthite crystals, and to a less extent of their multiple lamellæ due to albite twinning. Examination by Becke's method shows that there is no difference in refractive index between the substance of the mantle and the orthoclase phenocrysts, so that the two are to be distinguished (especially in ordinary light) by the differences of limpidity, while the higher index of the anorthite is strongly marked. The extinction angle of 11° in sections parallel to b (010) already mentioned indicates that the mantles are of soda orthoclase.

The border shows a well-developed micropoikilitic structure, since it contains like the groundmass many small augite and magnetite grains. In consequence of this there is scarcely any difference to be observed in ordinary light between the mantle and the surrounding groundmass, which seems to come quite up to the edges of the feldspar phenocryst.

Klein observed this feature in several rocks of the region, and Bucca likewise mentions a similar mantle in describing the leucite-phonolite of Bagnorea.

This mantle must be carefully distinguished from the phenocrystic crystal, as it is evidently the product of a distinct and later period of growth, and is almost identical with the holocrystalline groundmass. The only difference between the two is that under the influence of the pre-existing feldspar phenocryst the orthoclase substance crystallized as a single individual, the orientation of this later growth being determined by the nuclear crystal, and small crystals of augite and magnetite being included in a normal way. In the other part of the groundmass, away from the orientating influence of the large feldspar phenocryst, the orthoclase substance crystallized at many points as separate small individuals with diverse orientations, forming a normal trachytic groundmass.

The frequency with which plagioclase is surrounded by orthoclase in parallel position is well known and is noted by Rosenbusch,[1] though the present case differs somewhat from those mentioned by him. We do not have here the production

[1] ROSENBUSCH, Mikr. Phys., I, 638.

of definite crystal forms, but rather the orientation of the groundmass into micropoikilitic patches, though the principle involved is the same in both. Similar mantles of alkali feldspar about labradorite have been observed by Iddings[1] in rocks of the Yellowstone Park, by Pirsson[2] in the syenite of Yogo Peak, Montana, by Merrill[3] in rocks from Montana, and by Kolenko[4] in trachyte from New Zealand.

The borders in question are closely analogous to the micropoikilitic patches of quartz described by Miss Bascom,[5] Iddings[6] and Clements,[7] especially the last. Miss Bascom shows reasons for thinking the structure in the South Mountain rocks to be of secondary origin, while at the Electric Peak they are primary, as they also probably are in the Michigamme District according to Clements.

In the case before us the evidence is entirely in favor of their primary origin. As will be seen the phenomenon was observed in many other rocks of the Italian volcanic regions. These rocks are all comparatively recent lava streams, fresh and unaltered, so that there can be no appeal to metamorphic processes. The whole appearance of the border, with its included grains and its identity with the groundmass (except in its individual orientation), leaves no doubt that the effect is due simply to the orientating influence of the feldspar phenocrysts during solidification of the groundmass magma.[8]

The remaining phenocrysts are of augite and biotite, but offer few features worthy of note. In the normal gray vulsinite the augites—both phenocrysts and groundmass crystals—are of a pale olive green, while in the eutaxitic brown streaks they are of a bright golden-yellow color. The biotite phenocrysts are pale

[1] IDDINGS, JOURNAL OF GEOLOGY, III, 940, 941, 1895.

[2] PIRSSON, Am. J. Sci., L, 471, 1895.

[3] MERRILL, Proc. U. S. Nat. Mus., XVII, 645, 1894.

[4] KOLENKO, Neu. Jahrb., 1885, I, 9.

[5] F. BASCOM, this Journal, I, 816, 1893.

[6] J. P. IDDINGS, Electric Peak, 12th Rep. U. S. G. S., 589, 1892.

[7] J. M. CLEMENTS, this Journal, III, 814, 1895.

[8] Both Klein and Bucca consider them primary but late growths of orthoclase.

brown, irregular in outline and show without exception great "magmatic" alteration. The product is largely magnetite with little augite, and penetrates deeply and irregularly into the crystal. Magnetite is quite abundant, both in the groundmass and as phenocrystic grains. The groundmass is typically trachytic, and consists essentially of a holocrystalline cement of soda orthoclase flakes and laths, which latter are more abundant in the gray vulsinite than in the brown streaks. There is little evidence of flow structure. With these are numerous grains of yellow or greenish augite, magnetite grains and some apatite needles and grains of titanite. There are also seen some small crystals of a peculiar brown hornblende, which will be described at length later. No glass is present and the rock does not gelatinize with acids.

Here and there one sees coarse-grained, holocrystalline clusters of large augite, plagioclase, orthoclase and magnetite grains, which are probably segregations, as Klein suggests. The augite is generally bright golden-yellow, but a few pale green diopside grains are to be noticed. It is xenomorphic towards the feldspars, filling the interstices between them. The feldspars contain large dusty apatite crystals.

Three analyses of this rock are inserted here.

	1	2	3
SiO_2	59.22	57.97	58.21
TiO_2			Tr
Al_2O_3	18.56	17.65	19.90
Fe_2O_3		0.63	4.07
FeO	6.06	7.50	0.87
MnO		0.09	
MgO	1.12	1.71	0.98
CaO	2.96	5.53	3.58
Na_2O	4.87	1.50	2.57
K_2O	6.66	5.31	9.17
P_2O_5		0.42	not det.
Ignit.	1.14	1.82	0.74
	100.59	100.13	100.09

1. Vulsinite, Nassini's Quarry, Bolsena, VOM RATH, op. cit., 291.
2. " Bolsena, Ricciardi anal. KLEIN, op. cit., 8.
3. " Bolsena (665), Washington anal.

From the above description and analyses we may then define the *vulsinites* as effusive rocks *occupying an intermediate position between the trachytes and the andesites.* They are characterized mineralogically by the presence of alkali feldspar with a large amount of basic plagioclase (labradorite to anorthite) together with augite and diopside. Hornblende and biotite are not abundant in the type specimens, though they may be present in large amounts in other varieties, as will be seen later. Olivine is wanting, or if present is so in only accessory amounts. Chemically they are rocks of medium acidity, SiO_2, from about 55 to about 60 per cent., though it may run slightly above or below these figures. Alumina and iron are present in medium amounts, magnesia is low, lime rather high (3 to 6 per cent.), and alkalies (especially potash) high. Of the analyses above No. 3 may be regarded as typical. From an examination of this it is seen that after the formation of magnetite and pyroxene considerable lime is left over. Since part, if not most, of the alkali feldspar is a soda orthoclase and the amount of soda present is small this lime must go to form anorthite.

Klein describes very similar rocks which belong to the vulsinites. Those from Torre Alfina and San Lorenzo, north of Lake Bolsena, are very high in silica and lower in potash (according to Ricciardi's analyses) than we would expect (*cf.* anal. 5, p. 565). Their groundmass is brown, phenocrysts of glassy feldspar, biotite and augite are visible, and they seem not to be quite fresh. Among the phenocrysts sanidine largely predominates over the plagioclase, which is basic. Some olivine is present, but since the magnesia is low its quantity cannot be very great. The groundmass is very glassy, the base being brown through the presence of globulites. Orthoclase, plagioclase and magnetite are present in the groundmass, but augite is not mentioned. These rocks seem to resemble those of Monte Amiata described by Williams, and their relations will be discussed later.

The "trachyte" of San Magno, to the west of the lake, approaches nearer to the Bolsena rock, the silica being 60.03 but the potash is still rather low, though higher than the soda

(anal. 4, p. 565). It is quite free from olivine. Plagioclase is abundant and basic, giving extinction angles up to 30° on each side of the twinning plane. The groundmass is holocrystalline and composed largely of orthoclase and plagioclase, with augite, biotite and magnetite. In it occur round spots of very feebly doubly refracting substance which closely resemble leucite. Klein comes to the conclusion, however, that these are not leucites, since only 0.28 per cent. of K_2O is extracted from the rock by HCl, but that they are of glass in a condition of strain. From his description they seem to be the same—or very similar to—certain spots in the groundmass of a leucite phonolite from Lake Bracciano, which will be described in another paper. These are of "pseudo-leucite," a mixture of nepheline and orthoclase probably due to the alteration of leucite crystals.

The "olivine-bearing andesitic trachytes" of Sassara and Mont' Alfina (Klein, p. 6) belong rather to a type of rock which will be described in the next paper than to the vulsinites. The silica is lower (56.32 per cent.) and magnesia quite high (anal. 6, page 565). Basic plagioclase phenocrysts, with extinction angles up to 30° on each side of the twinning plane are very abundant, more so than orthoclase. Olivine, augite and biotite also occur as phenocrysts. The groundmass contains little glass, and is made up of the same minerals that compose the phenocrysts, except that olivine is wanting.

Andesite.—An augite-andesite is met with as the last product of eruption at Monte Rado, west of Bagnorea, and is described by Klein (p. 32). This, it will be remembered, is one of Verri's five centers of activity, and probably poured forth at an earlier stage the leucitic lava streams met with at Sassi Lanciati, Bagnorea and Porano. It is without doubt one of the last eruptions of the Bolsena volcano. Monte Rado is described as a hill covered with scoriæ, lapilli and bombs, and the specimen examined by Klein comes from the upper part. As I could not visit the locality I quote from Klein's description.

The phenocrysts are of plagioclase, which is apparently labradorite, and shows zonal structure, augite, brown biotite and

olivine. These lie in a very glassy groundmass containing fluidally arranged plagioclase laths and augite microlites. Neither nepheline nor leucite could be detected. It is possible that a small amount of sanidine may be present. Klein remarks that, though the appearance and the presence of olivine would suggest a basalt, yet that the analysis (No. 7, page 565) does not agree with this determination, and that consequently it must be called an olivine-bearing augite-andesite.

Leucite Rocks.— In our classification of these rocks we are confronted with two difficulties which render the bestowal of correct names, in so far as this is an important matter, an affair of some doubt. The first is the fact, already mentioned, that the various types grade into one another mineralogically to such an extent that the drawing of hard and fast lines is rendered in many cases impossible.

The second difficulty is the fact that two separate systems of nomenclature have been proposed by leading petrologists for some of the leucite rocks. The following are the names of Rosenbusch[1] and Zirkel.[2] An effusive rock composed essentially of leucite and orthoclase Rosenbusch calls a leucite-phonolite, while Zirkel calls it a leucite-trachyte. If nepheline is added to the above combination it becomes, according to the former a leucitophyr, according to the latter a leucite-phonolite. It is unfortunate that such a diversity should exist, especially in the double use of the name "leucite-phonolite." It is true that it is an embarrassment which seldom confronts one, since both groups are of very rare occurrence. In the present case however we are, so to speak, in their native land, and a decision must be come to in regard to the matter. Zirkel's objections to Rosenbusch's use of the term leucite-phonolite seem well grounded, since through long use one connotes the presence of nepheline with the name phonolite. Another objection which might be brought up is that the name leucite-trachyte for this group of rocks has the priority, since it was used by vom Rath[3] as far back as 1867.

[1] ROSENBUSCH, Mikr. Phys., II, 621, 1887.

[2] ZIRKEL, Lehrbuch, II, 427, 1894.

[3] VOM RATH, Zeit. d. d. Geol. Ges., XIX, 584, 1867. Cf. ROSENBUSCH, II, 621.

It is true that Rosenbusch uses the term phonolite in a very broad sense, covering the leucite as well as the nepheline rocks. The advisability of such an extension of its meaning may well be doubted. As to the term leucitophyr used by Rosenbusch, I must agree with Zirkel in his objections to it, as a name which does not convey any idea of the presence of nepheline, and conveying the erroneous idea that a porphyritic structure is characteristic of it. Further discussion of this subject is uncalled for, but the terms leucite-trachyte and leucite-phonolite will be used in Zirkel's sense.

Leucitite.—Of true leucitites there seem to be comparatively few in this region compared with others of Italy, such as those of Bracciano and Albano. Klein describes eight which belong to this group, though they all carry a little plagioclase, and Bucca also notices a few. They are basic, with SiO_2 from 48 to 50, and Ricciardi's analyses show less K_2O than we would expect to find. Megascopically they are basaltic looking, dark gray and very fine-grained and compact, with only rare phenocrysts of leucite and augite. Their micro-structure is the characteristic one, well known to most petrographers, of a groundmass made up of round spots of leucite with interstitial augite needles.

The most typical of my specimens is from a flow near the lake shore, about half a kilometer north of Bolsena. Its color is dark gray with a slightly greenish tinge.

Under the microscope it shows the typical structure. Leucite crystals are extremely abundant in the groundmass, few being of phenocrystic dimensions. With them are some large green augites, a few biotite crystals almost wholly "altered," and one or two well shaped orthoclase phenocrysts. These lie in a cement composed of colorless glass, with a felt of slightly greenish augite microlites, some magnetite grains and very few plagioclase laths.

The leucites, which show feeble double refraction, seldom reach a diameter greater than $0^{mm}.25$, and from this run down to microlitic dimensions. These smallest leucites show only

rounded outlines, but those of a larger size offer more variety. While some give sharp, normal, eight sided sections, with a few small, isolated inclusions, the greater number show more or less perfect skeletal forms. Their sections consist of simple four-armed crosses; eight-rayed stars with four alternate arms larger than the intervening ones, and thick at the ends or with a short process projecting from the end on each side; six-rayed stars with thick and equally developed arms at angles of 60°; finally, sections resembling equilateral, spherical triangles in outline, generally with triangular spots of glass at the apices.

The forms are evidently due to sections of skeleton crystals, and all may be referred to leucite skeletons like those described by Senigaglia[1] in a lava of 1753 from Vesuvius. They are developed not so much along axes as along planes from the center of the crystal to all the trapezohedral edges, the crystals being really trapezohedrons with deeply sunken faces and high salient edges.

Similar forms are to be found in other Italian leucitites, as from Lake Bracciano and the Alban Hills. Pirsson[2] has observed almost identical forms in rocks from the Bear Paw Mountains in Montana and gives an interesting discussion of their growth to which the reader is referred.

Another typical leucitite comes from Sassi Lanciati (Tossed Rocks), a locality about 2^{km} south of Bolsena on the lake shore where the road passes a lava stream about 10 meters high, showing well developed columnar structure. In the early days of geology this was apparently a well-known and oft-cited locality, but more accessible and better examples of this structure have thrown it into oblivion.[3]

The rock is described by Klein (p. 21), and is very similar to the first one described in this paper. It may be noted however that the inclusions in the leucite are rings of augite microlites arranged tangentially near the borders, and that no skeleton

[1] SENIGAGLIA, Neu. Jahrb., B. Bd. VII, 418, 1891.

[2] PIRSSON, Am. J. Sci., I, 1896.

[3] VOM RATH, op. cit., 292.

forms are present. Plagioclase is almost wholly lacking. Its specific gravity is 2.311 at 26° C.

With the leucitites may be classed the rock from a flow at the Osteria di Biagio, on the road from Orvieto to Bolsena. It is rather a nepheline leucitite, as it contains considerable nepheline in the groundmass. Its rather dark greenish gray groundmass is compact, but shows some narrow vesicular cavities, generally in planes parallel to each other as determined by the flow. In the groundmass are many small clear leucite phenocrysts and a few small black augites. Into the cavities project very many small stout hexagonal prisms of nepheline, which are coated with an opaque white substance, but are clear grayish white within.

Its appearance in thin section closely resembles that of the leucitites already described, the leucites being round, with feeble double refraction, and with included rings of augite microlites. The pyroxene of the interstitial groundmass is an ægirine-augite, and the base generally exhibits faint double refraction. Examination with acids shows that this is largely nepheline, though a small amount of glass seems to be present. No crystal sections of nepheline were to be found, and in the body of the rock it acts as cement and is undoubtedly the last product of crystallization. In the groundmass a few small colorless laths were to be seen which may be referred to orthoclase, indicating a transition toward the leucite-phonolites.

As phenocrysts appear large and much cracked leucites, green augites, a few fair-sized crystals of orthoclase much broken and corroded, which are usually associated with the augite and appear to belong to the same period of crystallization, and finally a a few remains of biotite crystals altered as usual to a granular mass of augite and magnetite. The interior of one of these last contains fine parallel straight lines of minute magnetite grains lying at an angle of about 60° with the basal plane.

The leucitites described by Klein agree on the whole so closely with the above that it is needless to do more than refer to them. Analysis No. 8, page 565, of the leucitite of Sassi Lanciati, has

been selected as typical of Ricciardi's closely agreeing analyses of this group. We may note here that they are low in silica, high in iron, lime and magnesia, and surprisingly low in alkalies, considering the amount of leucite present.

Leucite-phonolite.— Representing this group are specimens from two localities, which differ somewhat from each other and which may be described separately.

Two, from above St. Trinita near Orvieto, are from different parts of the same flow, one being compact while the other is highly vesicular, though not enough so to be a true scoria. The groundmass is light gray and in it lie many large, sharp leucite crystals up to $1^{cm}.5$ in diameter, of a pale yellowish white color and waxy luster. They are much cracked and contain large inclusions of augite and magnetite, generally as a nucleus in the center. Lining the sharp trapezohedral cavities left by leucites which have fallen out is a thin white crust, which under a lens is seen to be minutely mammillary.

In thin section the large leucites, which have generally lost much of their substance through cracking and falling out, show quite strong double refraction. The edges of their sections are sometimes corroded, and in these places one observes that they are separated from the groundmass by a narrow border of clear colorless substance, with a refractive index slightly higher than that of the leucite. This is the white crust just mentioned. Between crossed nicols it shows weak double refraction, and in places a radially fibrous, spherulitic structure is developed, the fibers diverging toward the leucite. Definite determination could not be made, but it is probable that this border consists essentially of orthoclase, perhaps due to a solution of the leucite in the magma.[1]

The green ægirine-augite phenocrysts are somewhat fragmentary. They show distinct pleochroism; **c** slightly bluish green, **a** light yellowish green. A very few orthoclase and one or two labradorite phenocrysts are present.

[1] It may be noted that in a leucite-phonolite from Latéra Bucca (p. 27) observed an apparent formation of leucite out of orthoclase, while in that from Acquapendente he notes the reverse process.

The groundmass is rather trachytic in character, as many orthoclase laths — best seen with crossed nicols — are present, showing decided flow structure. With them are numerous small leucite crystals, with rounded outlines, containing a few sporadic inclusions and an abundance of prismatic microlites of ægirine-augite, with $\mathbf{c} \wedge c = 38°$. Some magnetite is also present. All these small crystals lie in a colorless base of low refractive index, which in many places shows weak double refraction, and which treatment with acid proves to be nepheline.

The other specimen of leucite-phonolite is from the large quarries immediately to the north of Bagnorea, east of the lake, whence the slabs are exported for paving stones. The same rock is described by Bucca,[1] who does not mention nepheline, though he speaks of the base as easily gelatinizable and rich in soda. It is ash gray and fine-grained, with rough texture and small cavities whose walls bear leucite but no nepheline crystals. The specific gravity was found to be 2.648 at 27° C.

Examined under the microscope the leucites and pleochroic ægirine-augites show no specially noteworthy features. The few well-shaped orthoclase phenocrysts often carry a mantle of later alkali feldspar substance like that previously described. There are also a few biotite phenocrysts which have been entirely altered to augite and magnetite in the usual way.

In the groundmass there are abundant small leucites almost free from inclusions, stout ægirine needles and some magnetite grains. Orthoclase laths are larger and more abundant than in the rock just described, and there are a few flakes of brown biotite which are among the last products of crystallization. These lie in a nepheline base similar to that of the last rock.

Klein describes a leucite-phonolite from Gradoli, northwest of the lake. Its megascopic appearance is that of a phonolite. In thin sections appear as phenocrysts a green pleochroic augite (probably ægirine-augite), some large leucites and a few sanidines. In the holocrystalline groundmass nepheline, leucite and

[1] BUCCA, op. cit., 20. Also Boll. Com. Geol. Ital., XIX, 58, 1888.

sanidine occur in well-formed crystals, along with biotite, magnetite and apatite. A little haüyne occurs, but augite is not spoken of as present in the groundmass. There is unfortunately no analysis of this rock. Klein describes also two rocks which may belong here, one from La Canonica and one from Proceno. The former is apparently a transition type towards the leucitites, the latter is noteworthy as containing haüyne and also a very basic plagioclase. Its high percentage of silica and low lime and magnesia are also remarkable (anal. 10, page 565).

The "leucitophyr" of vom Rath[1] is probably a leucite-phonolite since he mentions a colorless weakly refracting mineral as the last product of crystallization. He thinks this may be feldspar but it answers to the characters of nepheline. All of the leucitic-trachytes as well as some of the leucitophyrs, described by Bucca, probably belong here. This is shown by their augite being pleochroic, the frequent presence of haüyne, and the presence in the groundmass of a "colorless glassy base," rich in soda and easily gelatinizable (*op. cit.*, p. 19).

I may add that a specimen from Acquapendente in the collection of Yale University closely resembles my specimen, gives abundant gelatinous silica with acids, and is apparently identical with one from that locality described by Bucca. According to Scrope,[2] and apparently also according to Ricciardi[3] the lavas of Acquapendente are connected with the volcanic center of Radicofani to the north.

Leucite-trachyte proper is not definitely known from this region, though possibly one or two of Bucca's rocks belong here.

Leucite-tephrite.—Rocks belonging to this group are very abundant, and transition forms to the other types are common. Of my specimens only a few will be described in detail, as Klein's descriptions cover the ground very fully. The rocks of this group are generally of quite basaltic appearance, and resem-

[1] VOM RATH, op. cit., 290.

[2] SCROPE, Volcanoes, London, 1862, 354.

[3] RICCIARDI, Terreni Vulcanici, Florence, 1879, 133.

ble much the leucitites megascopically, though leucite is less common as phenocrysts than augite. Their microstructure is quite different and generally doleritic. The silica percentage is about 52.

The rock from Monte Cavallo south of Orvieto, a flow with columnar structure mentioned by vom Rath, and that from Porano, southwest of Orvieto, a flow which Verri considers as belonging to the Monte Rado center, are dark gray, fine-grained rocks showing few phenocrysts, and these small and entirely of dark green augite. Its specific gravity is 2.763 at 26° C.

Under the microscope they show a doleritic structure. In the groundmass leucite predominates as irregularly shaped crystals and patches, which correspond in function to the augite of ophitic diabase. It shows weak double refraction, with the usual polysynthetic twinning, and containing few inclusions of glass and augite. Lying between or imbedded in the leucites are long prisms of augite, together with plagioclase laths whose extinctions correspond to those of a basic labradorite. Some magnetite is also present, as well as a small amount of colorless glass. A few orthoclase laths were seen, but no nepheline could be detected.

The augite is grayish green, and shows an extinction angle of 41° with the axis *c*. Associated with it is a clear brown mineral, occurring here and there on the ends and sides of the augite crystals, and in small quantity as separate individuals of a somewhat fragmentary character, which show few crystal planes. When occurring with the augite the two are not separated sharply but shade into one another, the green color gradually giving place to the brown, the cracks running uninterruptedly through both. The mineral has a slightly lower refractive index than the augite, but strong pleochroism; parallel to *c* (assuming this to correspond to the vertical axis of the augite) it is dark hair brown, and at right angles to this, light yellowish brown and pale greenish yellow. The extinction angle with the cleavage cracks, which are quite well marked, reaches 17°.

These characters made it seem probable that we have here a growth of acmite about augite, as the last stage of pyroxenic crystallization. Further examination, however, showed that the bisectrix nearest the vertical axis is not $\mathfrak{a}$, as is acmite, but that of least elasticity $\mathfrak{c}$. The greater number of crystals are cut more or less nearly parallel to the vertical axis, but search revealed a few cases of parallel growth where the augite and the brown mineral were cut horizontally. In these the cleavage cracks of the augite formed an angle of 88°, while those of the external brown mineral formed angles of 122° with each other, the planes *b* (010) and *m* (110) being present, and the direction of least absorption being parallel to the clinopinacoid. The mineral is therefore an amphibole and may be referred to barkevikite, with whose characters it closely agrees. It is regretted that a chemical examination of this interesting mineral could not be made, but the small amount of the substance and its intimate association with the augite, rendered a mechanical separation impossible.

Bucca[1] mentions a brown pleochroic hornblende associated with the augite of a leucite-tephrite (?) from Poggio Pilato near Valentano, and also a similar amphibole in a leucite-trachyte from Casaccia on Lake Vico.[2] According to de Stefani[3] Rosenbusch observed a mineral like that described above in the "basalt" of Radicofani. Rosenbusch[4] also notes a brown hornblende surrounding augite in an Ischian trachyte.

It may be mentioned that since the chemical character of the amphibole pointed to the pyroxene being a soda-rich ægirine-augite, an examination was made to determine the character of the bisectrices of the latter. This showed that the bisectrix nearest the vertical axis was $\mathfrak{c}$, so that it is an augite.

Another leucite-tephrite from below Sta. Trinità near Orvieto may be the same as that mentioned by Klein from this locality.

[1] Op. cit., 28.

[2] BUCCA, Boll. Com. Geol. Ital., 60, 1888.

[3] DE STEFANI, Boll. Com. Ital., 224, 1888.

[4] ROSENBUSCH, Mikr. Phys., II, 584, 1887.

It resembles the preceding, though it is much finer grained, and the leucite is seen to be quite subordinate in amount as compared with the augite and plagioclase. This last is quite basic and is a true bytownite.[1] Quite noticeable in the sections are many small flakes of brown biotite, which have given rise to patches of a bright green, finely-granular viridite, probably through atmospheric alteration. None of the other minerals show signs of decomposition, except the magnetite, which is sometimes accompanied by spots of limonite and bright orange hematite. The augite is pale gray and none of the brown hornblende is present.

Most of the leucite-tephrites described by Klein seem to resemble the above and call for no special notice. Exception must be made for those from Montalto, southwest of the lake, which Verri regards as a distinct eruptive center. They approach augite-andesites in character, but carry olivine phenocrysts, and small leucites only in the groundmass, so that Klein calls them "leucite-tephrites with accessory olivine." In mineralogical composition they correspond to a leucite-basanite, but their high content of silica allies them with the tephrites. (*Cf.* anal. 11, page 565.)

The phenocrysts are of green augite, a basic plagioclase, magmatically altered biotite, olivine, magnetite and apatite. The groundmass is andesitic in structure and consists largely of plagioclase laths, augite crystals and magnetite grains, with small colorless spots which were identified with leucite. All these lie in a glass base. It is noteworthy that in one very glassy specimen no leucite was to be found, while the other minerals remained as before.

Leucite-basanite.—None of my specimens belong here, so I may briefly mention some described by Klein as "leucite rocks of doleritic habit." All his specimens come from the southern part of the region. They are distinguished from the true tephrites by their constant olivine content and structure, and Ric-

[1] ROSENBUSCH (Mikr. Phys. II, 762, 1887) mentions the occurrence of acid plagioclase in a leucite-tephrite from "Orvieto."

TABLE I.

	1	2	3*	4	5	6	7	8	9	10†	11	12	13
SiO_2 ..	59.22	57.97	58.21	60.03	63.26	56.32	56.42	48.89	55.10	59.69	55.11	52.16	48.09
Al_2O_3 .	18.56	17.65	19.90	17.05	16.05	18.17	16.81	16.05	19.20	16.22	16.07	15.03	13.60
Fe_2O_3 .	....	0.63	4.07	1.83	1.04	2.23	3.26	1.80	....	1.93	3.04	3.17	2.52
FeO...	6.06	7.50	0.87	4.15	6.13	6.47	6.92	10.09	6.86	8.17	8.46	8.42	9.36
MnO. .	....	0.09	....	0.09	0.14	....	0.23	0.43	....	0.44	....	0.24	0.10
MgO ..	1.12	1.71	0.08	1.12	1.29	2.84	3.50	3.98	1.18	2.72	3.10	4.69	6.75
CaO...	2.96	5.53	3.58	6.58	5.50	5.33	5.64	11.88	3.75	4.80	6.46	10.07	13.05
Na_2O..	4.87	1.50	2.57	2.31	1.62	1.80	1.21	1.81	2.68	1.03	1.58	2.38	1.41
K_2O...	6.66	5.31	9.17	5.12	3.18	4.18	3.07	3.00	10.78	3.09	5.07	2.47	3.07
P_2O_5..	....	0.42	....	0.42	0.51	0.34	1.08	0.29	....	trace	0.75	1.15	0.41
SO_3...	....	....	....	....	....	....	....	0.59	....	0.64	....	....	....
Ignit...	1.14	1.82	0.74	1.42	1.57	2.15	2.25	1.39	1.22	1.54	0.89	0.72	1.62
	100.59	100.13	100.09	100.12	100.29	99.83	100.39	100.19	100.77	100.27	100.53	100.50	99.98
Sp. Gr.	2.55	2.45	....	2.54	2.42	2.52	2.63	....	2.50	....	2.55	2.75	2.76

* Contains trace of TiO_2.

† Contains trace of Cl.

1. Vulsinite, Nassini's quarry, Bolsena, vom Rath, op. cit., 291.
2. Vulsinite, Bolsena, Ricciardi, Klein, op. cit., 8.
3. Vulsinite, Bolsena, No. 665, Washington.
4. Vulsinite, San Magno, Ricciardi, Klein, op. cit., 10.
5. Vulsinite (?), San Lorenzo, Ricciardi, Klein, op. cit., 3.
6. "Andesitic Trachyte," Monte Alfina, Ricciardi, Klein, op. cit., 7.
7. Augite-andesite, Monte Rado, Ricciardi, Klein, op. cit., 33.
8. Leucitite, Sassi Lanciati, mean of two, Ricciardi, Klein, op. cit., 20.
9. Leucite-phonolite (?), Nassini quarry, Bolsena, vom Rath, op. cit., 290.
10. Leucite-phonolite (?), Proceno, Ricciardi, Klein, op. cit., 26.
11. Leucite-tephrite, Montalto, Ricciardi, Klein, op. cit., 28.
12. Leucite-tephrite, Monte Bisenzio, Ricciardi, Klein, op. cit., 19.
13. Leucite-basanite, Valentano, Ricciardi, Klein, op. cit., 23.

ciardi's analyses show them to be very basic, with about 48–49 per cent. of silica.

According to Klein they are gray, medium-grained rocks, somewhat vesicular. Leucite, augite and olivine appear as phenocrysts; plagioclase is subordinate in amount both as phenocrysts and in the groundmass. Klein remarks that as olivine increases plagioclase decreases, though this relation has apparently no influence on the structure. The groundmass is made up largely of augite, with leucite, magnetite and plagioclase, occasionally biotite and haüyne, and in one instance nepheline. The presence of a glass base is not mentioned.

Chemical composition.—A selection of what seems to be the best and most typical of Ricciardi's analyses is given in the table, together with the two of vom Rath. No. 3 was made by myself in the Mineralogical-Petrographical Laboratory of Yale University, with the assistance of Professor L. V. Pirsson. I gladly take this opportunity of expressing my sincere thanks to him for his valuable assistance and advice. The general discussion of the analyses will be reserved for the final paper of the series.

HENRY S. WASHINGTON

DRAINAGE MODIFICATIONS AND THEIR INTERPRETATION.[1]

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[1] Published by permission of the Director of the U. S. Geological Survey.

PART I. PRINCIPLES OF DRAINAGE MODIFICATION.

(1) RELATION OF DRAINAGE FORMS TO LAND FORMS.

THE great advancement in the interpretations of physiographic forms which has marked the last decade has led to a better understanding of the late geologic history of certain continental areas than has ever been attained from the study of the sediments deposited around their margin. Although such important results have been derived from this study in so short a time, they are but scattering chapters in the complex history of continental development, and much yet remains to be done before a clear insight can be obtained into the various conditions of the past. Our success in reading this history lies in following out all of the lines of corroborative evidence available, in the hope that where the evidence along any one line is weak, that along another may be strong and complete, enabling us to build up a more or less perfect whole from the different classes of facts.

The process of erosion, according to Gilbert,[1] consists of three parts: weathering, transportation, and corrasion; and is modified by three conditions: declivity, character of rock, and climate. Physiographic forms resulting from the process of erosion are necessarily modified by any change in the above mentioned causes and conditions. But since streams are the principal agents in transportation and corrasion; and since transportation and corrasion are dependent upon weathering (which is modified by climate), declivity, and character of rock, it follows that any change in the causes or conditions affecting erosion will modify the action of the streams and any modification of the action of the streams will tend to change their alignment in accordance with the changed conditions.

This intimate relation between stream alignment and physiographic forms suggests the advisability of thorough study of drainage systems, in the hope of finding some record of past conditions which will throw additional light on the question of the physiographic history of continental areas.

[1] Geology of the Henry Mountains.

(2) CLASSES OF DRAINAGE ADJUSTMENTS.

Neglecting the catastrophic effects of glaciation and volcanic action, drainage modifications may be divided into three classes: (1) Changes marking the progress of a river through a normal cycle of development. (2) Adjustments due to character of rocks and geologic structure. (3) Rearrangements caused by local uplifts or depressions of the earth's crust.

Class 1. Changes during the normal development of a stream.— The modifications falling within this class are well understood, having been thoroughly worked out by Davis and others, but for the sake of clearness will be briefly restated.

A cycle in river development, according to Davis,[1] consists of the interval of time during which a river reduces the land within its watershed to baselevel. Let us for a moment glance at the process by which this is accomplished. In its youth the grade of the stream is necessarily great, since the surface of the land must be far above baselevel. With a steep gradient the current is everywhere rapid, and all of the refuse worn from the land by weathering and corrasion is carried by the force of the current into the sea. The stream so loaded becomes an abrading instrument of great power, and its channel soon partakes of the character of a rocky gorge or canyon. That portion of its course which is nearest the mouth of the stream will first be reduced approximately to the baselevel of erosion. As soon as that is accomplished the gradient becomes so low that the stream can no longer carry its burden of waste to the sea. A portion of its load will be dropped in the channel deflecting the current from its original course and causing it to cut away its banks on the side toward which the current sets. As the current is lessened by these meanders, its carrying power is diminished and it is forced to give up more of its load which is added to the barrier already existing and which tends continually to deflect the stream into broader and broader meanders. Thus in progressing from youth to old age, the stream changes its appearance in accordance with the changed conditions which surround it. Conse-

[1] The Rivers and Valleys of Pennsylvania, Nat'l. Geog. Mag., Vol. I, p. 203.

quently the history of this portion of the cycle is recorded, not alone in the sculptured forms of the land, but also in the changed alignment of the streams.

As the stream approaches extreme old age, its gradient grows less and less, and the divides between adjacent streams become so low that many adjustments are required before a perfect balance prevails between the contending streams. This is due to the fact that in this portion of the cycle the streams are but slightly prepared to defend themselves, and any stream handicapped by a circuitous route to the sea will eventually suffer loss of drainage area at the hands of a neighboring stream.

It would be almost impossible to read the history of drainage developments, unless we could go back for our beginning to some period in which drainage conditions are known. During its period of youthful development, a stream leaves but few traces by which, in after years, we may judge of the extent of its drainage basin, or of the conditions under which it labored; during its maturity its records are equally unintelligible, for they tell us nothing of the local conditions which surrounded it; but in its old age we can say with confidence that, so far as it is untrammeled by local obstacles (and local obstacles are rare in this stage of erosion), it is evenly balanced against the surrounding streams. If then we find traces of a stream having reached old age, we can calculate with reasonable certainty the extent of its basin, or if its basin does not extend to the limit which should mark the contending streams, we may be assured that local obstacles interfered with its normal development. Thus the last stage of the life history of a river implies certain physical conditions, consequently it is the period to which we must refer in undertaking to read the history of drainage developments.

Class 2. Adjustments due to rock character and geologic structure. —Drainage modifications which fall within this class have received the attention of our ablest physiographers, hence their mode of origin is well understood. Gilbert has shown how streams, flowing on inclined beds of alternating hard and soft

rock, will naturally tend to migrate down the slope of the beds, producing a change in the alignment of the streams. Davis has fully demonstrated that streams flowing over folded and faulted rocks will first have their positions determined by the synclinal folds of the structural surface, and then they will migrate to the anticlines, or in technical terms will change from consequent to subsequent streams.

Changes due to these conditions are of great importance in drainage studies, but, since complicated geologic structure is limited to small areas compared with the continental mass, such conditions can prevail only in a prescribed area, and consequently affect but a limited number of streams. Hence in a general study of drainage changes, this class does not deserve the prominence that has been attached to it.

Class 3. Rearrangements caused by radial crustal movements.— If the earth's crust remained entirely free from movement, the history of the drainage would be extremely simple, consisting of but a single cycle; and its barrenness of striking features would only be equaled by the monotonous expanse of baseleveled plain which would be produced during the cycle. The present diversity of surface features is positive evidence that such has not been the case — that the crust of the earth has suffered repeated oscillations which have prevented the formation of such an extensive baseleveled plain, and at the same time have complicated the drainage history to a remarkable extent.

Recent studies of the Mesozoic and Cenozoic peneplains of the southern Appalachians seem to demonstrate that this region has suffered two kinds of crustal movements in post-Palæozoic time. Both of these come under the class of radial movements, but they differ in the intensity of the deformation of the base-level and in their lateral extent. For convenience of study we may divide them into general and local oscillations. As the name implies, the first class embraces those movements of elevation or depression which are of continental or semi-continental extent. Since the amount of movement is slight compared with the horizontal extent, the deformation will be so slight as to be

unrecognizable. These movements may produce a complete transformation of the drainage features of a land area by causing a portion of it to be depressed below drainage level; or they may cause the revival, or rejuvenation of the streams by lifting the land above its previous position. In any case the modifications arising from such movements will fall under the first class, or those due to the natural course of events in a normal cycle of development.

Crustal movements of the second, or local class affect but a limited area. They consist of uplifts or depressions which reach a maximum along an axial line, grading off to the undisturbed strata at no great distance on either side. The local movements which have occurred in the past have not generally been intense enough to cause a perceptible dip of the rocks, but they have elevated the surface into broad ridges, or depressed it into shallow troughs.

The effects of these local movements upon the drainage must have been very different from the general movements. They would cause no general revival, but would affect the streams locally, and consequently their effect in producing rearrangement must have been very much more potent. The principal object of this paper is to study the effect of these local movements upon the streams; to endeavor to establish the criteria by which the changes due to this influence may be recognized; and lastly to apply these criteria to a continental area, and by their assistance endeavor to read the history of the region in question.

(3) IDEAL CASES ILLUSTRATING THE EFFECT OF LOCAL EARTH MOVEMENTS.

In studying this subject in the field, the observer is frequently confused by local conditions of geologic structure and alternation of hard and soft strata, which apparently overshadow the more subtle influence of crustal warpings; although the latter may, in a general way, be the dominating force which has shaped the drainage systems. In a theoretical consideration of

the question, however, we can eliminate the local disturbing conditions and thus determine the true value of surface warpings as stream modifiers.

We will then assume a land area in which the strata are horizontal and perfectly homogeneous and, for farther simplification, will suppose that its surface has a regular descent from a low, interior water-parting toward the sea on either side. If in such an area the climatic conditions are the same on either side of the dividing ridge, the rate of erosion would be the same and the opposing streams would be held in a delicate balance against each other. The amount of energy expended by one stream in corrading its channel would necessarily be the same as that of its antagonist and the gradient of the streams, in their various portions, would show a close correspondence.

(*a*) *Effects of elevation.*—If then an uplift should occur across one stream a short distance from the divide, it would not materially change the ratio of energy expended by the streams in the corrasion of their channels; each would be increased by the increased gradient, but the energies would be expended in very different portions of the channels. The stream which is not crossed by the axis of uplift would have its gradient near headwaters increased, and consequently the greater portion of its corrasive energy would be concentrated upon the divide at its head. The stream which is crossed by the axial line would have its gradient near headwaters diminished, while below that line its gradient would be increased, consequently a large amount of its energy would be transferred to that part of its course which is below the axis of uplift, and almost none would be used on the divide against which its antagonist is concentrating all of its force. There can be only one result, and that is the gradual eating away of the divide on the side opposite the uplift, and the consequent migration of this divide toward the axis of elevation. It matters not how slow nor how slight is this uplift, its effect will be the same in character, though differing in amount of modification produced. The principle is fundamental and must apply in all cases.

Figures 1 to 4 are a graphic representation of the manner in which such an uplift would affect the drainage and cause the divide to migrate towards its axis. Let *A*, *E* (Fig. 1) represent a

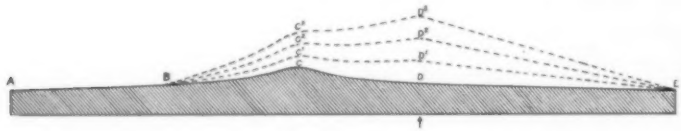

FIG. 1.

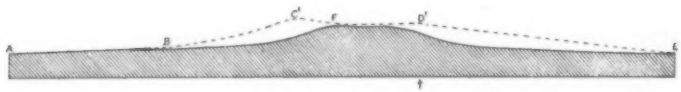

FIG. 2.

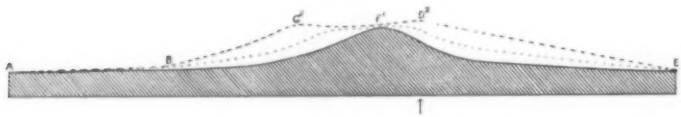

FIG. 3.

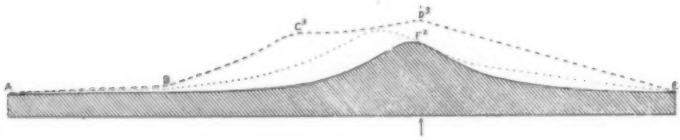

FIG. 4.

cross-section through the divide *C* separating two streams flowing in opposite directions, the profiles of which are represented by the curved lines *A*, *B*, *C* and *E*, *D*, *C*. Let us suppose still farther that the streams are balanced against each other, consequently the profile will be symmetrical. It is evident that the divide *C* will remain stationary unless some external cause interferes to disturb the delicate balance now maintained. Suppose that such an external cause elevates the strata at the point *D*. Since we are dealing with the effect of local movements, we will suppose that this movement extends each way only so far as the points *E* and *B*. Now if the point *D* were elevated by the force

represented by the arrow, it would take successively the positions D^1, D^2, and D^3, and the divide C, if it remain stationary, would occupy the positions C^1, C^2 and C^3. If the movement were sufficiently rapid, so that erosion produced no sensible effect, it is obvious that when the point D reached D^3, it would be at a greater altitude than C^3, and consequently the divide would be shifted from C to D; thus the stream flowing toward E would be beheaded and the stream flowing toward A would be increased by the beheaded portion.

It is not at all probable that the great majority of crustal movements are rapid enough to produce this effect. Let us examine the problem and see if a slower rate of elevation would affect the drainage.

Suppose that the rate of elevation is but little more than the rate of erosion. Under the supposition the condition of the divide would be represented approximately by Figs. 2, 3, and 4. Generally the first result of the uplift is the formation of a barrier at the point D, but if the rate of movement is very slow and the rocks soft, the stream may cut away this barrier as fast as it is produced by the upward movement. The rising of the land and the cutting of the stream continue until the elevation reaches D^1; at that period of development the condition of the streams and the divides is shown in Fig. 2. The original surface is represented by the broken line, A, B, C^1, D^1, E. According to our assumption, the streams were nicely balanced against each other before the uplift occurred, hence the slightest elevation at D would raise a barrier in the pathway of the stream C, D, E, and while this stream may be able to remove the barrier, it involves a certain expenditure of time and energy which the stream A, B, C, is not required to make. Thus the effect of such a barrier is to retard the stream which it crosses, but in the case under consideration the uplift not only retards one stream, but it steepens the grade of the other and consequently accelerates its corrasive power near headwaters.

Under such favorable conditions, it would cut rapidly into the divide at C while the other stream is expending its energy in

keeping its channel free at the point *D*. The actual amount of corrasion accomplished by the two streams is probably not far from the same. The stream *A*, *B*, *C*, is accelerated greatly, but this acceleration is limited to its headwaters where its volume of water is small, hence its power of corrasion is not proportionately increased: on the other hand the stream *E*, *D*, *C*, is retarded at its headwaters, but accelerated in its lower course, and since its volume of water is greater at the point of acceleration, its power of corrasion is considerably increased, although its gradient is but slightly changed. This transfer of active corrasion from *C* to *D* is what weakens the stream *E*, *D*, *C*, and gives the stream *A*, *B*, *C*, its great advantage; for nearly all of the cutting of the latter stream is confined to the immediate vicinity of the gap. When the point *D* is elevated to D^1 the profile of the streams will be *A*, *B*, *F*, *E*, instead of *A*, *B*, *C*, *D*, *E*, and the divide will have migrated from *C* to *F*.

This process is continued as the point *D* is elevated. When it reaches D^2 (Fig. 3) the stream *E*, *F* will have been so handicapped by the uplift across its course and the stream *A*, *B*, *F*, so accelerated by the same movement that the divide will have migrated still further toward the axis of uplift and will occupy some such position as F^1. Again the uplift continues and the point *D* reaches D^3, and the divide F^1 reaches the position F^2.

The figures (1 to 4) would seem to indicate that the rate of migration is the same for a given amount of elevation whether the divide is near or far from the axis of uplift. Such can hardly be the case, for if the axis crosses the stream at some distance from its source it will be at a point where the gradient of the channel is less than if the axis were near the headwaters of the stream; consequently the stream which is retarded will suffer most at the first uplift and as a consequence the divide will tend to migrate rapidly. Later uplifts will occur at points where the gradient is steep and consequently they will have but little effect. In the case of the stream which is accelerated, the tendency will be different. At the beginning of the uplift the drainage basin is so far removed from the axis of the uplift that

its effects are somewhat feeble; but as the divide migrates toward the axial line the acceleration of the stream will become greater and its most effective work will be accomplished when the divide approaches close to the axis of elevation. In balancing the two processes, it seems probable that the former is the controlling element and that the divide migrates more and more slowly as it approaches the axis; and the duration of the last stage may be many times that of the first.

If the uplift continues indefinitely the divide will certainly reach the axis and there it will remain so long as the uplift continues, unless some more potent force causes it to change.

Under the last assumption the rate of the uplift is, at least, equal to the rate of corrasion. We must now consider the case when it is much less. This probably approaches more nearly the actual condition which has accompanied each movement in this province. Since the rate of elevation is less than that of corrasion, the streams can more than keep pace with the rising fold, and hence their profiles will change only in a nearer approach to baselevel and the migration of the divide toward the axis of uplift. The conditions remain practically the same as in the previous case, except that now the divides will migrate more slowly and will constantly approach baselevel.

If the axis of uplift corresponds with the original divide (Fig. 1), there will be no migration, for each stream will be accelerated equally, and each will concentrate its energies at the same point — the divide *C*. The position of the divide *C* will be maintained as long as the uplift continues, unless some external cause exerts a more powerful influence in an opposing direction.

(*b*) *Effects of depression.*— As we have already seen, any pronounced tilting of the surface of the earth tends to produce a migration of the divides in the region affected by the tilt, hence the principle of the migration of divides will apply equally well whether the movement be elevation or depression. And while in the great majority of cases of earth movements the effect is to elevate the land, there are well-marked cases of local

subsidences in the Appalachian province; and it is well to consider the case in detail so as to familiarize ourselves with the phenomena which it produces.

FIG. 5.

FIG. 6.

FIG. 7.

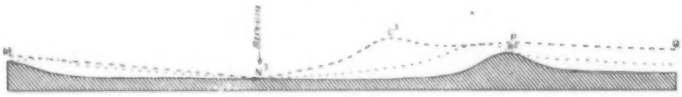

FIG. 8.

Starting with the assumption of two streams, *M*, *N*, *O* and *Q*, *P*, *O* (Fig. 5), equally balanced against each other, we will suppose a subsidence to occur at the point *N*, causing it to assume in successive order the position N^1, N^2 and N^3. It is obvious that if the depression is more rapid than the corrasion of the stream on either side of the depression, the stream will become ponded at the point *N*, and will, in all probability, seek an outlet at right angles to its former course and approximately along the axis of subsidence. If, on the other hand, the movement is so slow that erosion can keep pace with the depression the change will not be so radical, but in the end will result in approximately the same arrangement as sketched for the former case. It will be accomplished about as follows: In the first stage of the

movement, when N is depressed to N^1, the stream M, N, O will have been seriously retarded by the decreased gradient of that portion of its upper course which is within the limits of the crustal movement. In this first stage, as shown by Fig. 6, the stream has lost almost all of its gradient, and corrasion along the lower course of the stream has not been able to relieve the sluggish portion of its upper course. It is incorrect to consider the entire upper course as retarded; the portion below the axis of depression, or that portion which is tilted toward the head of the stream, is rendered sluggish; but that portion which is above the axis is considerably accelerated by the downward tilting and the stream will corrade its channel back into the former divide. The stream Q, P, O will suffer by the depression of its headwaters, and so will be deprived of the power to hold its own against the opposing stream. As in the cases already discussed this divide will migrate toward the weaker stream, or away from the axis of depression.

If the subsidence continues, the point N will soon be lower than the stream channel farther down, and consequently ponding will ensue, until the ponding waters can find an outlet in some other direction. This is supposed to have occurred in Fig. 7, and a transverse stream is located at the point where the axis crosses the course of the former stream. A new divide is thus formed between M and N, its position depending upon the readiness with which the waters find an outlet at N. On the other hand, the divide R will have migrated to R^1. In the last stage the divide S will have reached M and the divide R^1 reached R^2.

In comparing the results obtained when the movement is depression with those produced by elevation, it will be found that the changes are of the same character whether the movement is elevation or depression, or whether it is fast or slow. In all cases the divides will tend to migrate up the slope of the tilted surface, and they will so continue until the point is reached where the surface is unaffected, or else is inclined in another direction.

In the cases so far considered we have assumed that the process continues to its completion—that the uplift or depression was of such duration that the streams became perfectly adjusted to their changed conditions, and that the divides in all cases reached the highest point on the tilted surface. This is the ideal condition, but in reality it is probable that the movements were seldom of sufficient duration to produce this result. Hence in applying these principles in the field we must expect to find cases where the migration was but partial and the streams continue to head across the former axis of uplift. Also we have, in the foregoing cases, assumed the simplest conditions possible. Nowhere in actual practice will the physiographer have to deal with so simple a case as we have here assumed; he will find instead of homogeneous rocks a mass of alternating sandstone, shale and limestone which will greatly modify the results, and he will find complex geologic structure instead of the horizontal rocks in the ideal case. While the actual conditions in the field seem so different from those which we have assumed, the determination of the ideal case furnishes us with a law which applies to all cases, but under complex conditions its results are difficult to distinguish from those produced by other forces.

(4) LAW OF THE MIGRATION OF DIVIDES.

Whenever local radial movements occur in any region the stream divides in that area will tend to migrate; the direction in which they move will be determined by the character of the crustal movement; and the extent of the migration will depend upon the amount of movement and the local obstacles which the streams may encounter. If the movement is upward the divide will tend to migrate toward the axis of uplift; and if the movement continues long enough, and other conditions are favorable, it will reach the axial line and there remain. If the axis coincides with a divide already established it will hold the latter stationary, unless some stronger influence causes it to migrate.

If the movement is one of subsidence the divide will tend

to migrate away from its axis; and will continue in that direction until the streams attain a condition of equilibrium.

The migration of the divide away from the axis of depression generally results in the formation of a stream along the axial line; and the direction in which it flows will depend, in a great measure, upon the pitch of the axis of the fold.

Such is the law of the migration of divides, under the influence of surface warpings. It is probable that if such migrations have occurred in the past we can find some trace of the modifications thus produced and be able to determine the character, direction and extent of the movements, and from that form some idea of the physical condition of the continent in late periods of geologic history.[1]

MARIUS R. CAMPBELL.

U. S. GEOLOGICAL SURVEY.

[1] To be followed by Part II, Criteria for Determining Stream Modifications.

GLACIAL STUDIES IN GREENLAND. IX.

With one exception — the Igloodahomyne — the glaciers thus far studied have been dependencies of local ice-caps. Those first sketched were connected with the snow fields of the island of Disco. Those which we have just been considering were offsprings of the snow-cap of the Redcliff peninsula. We are now about to turn to the tongues, lobes and border of the great ice mantle of Greenland.

The order of study we have pursued has certain elements of advantage that may be noted before we pass on, as it may be helpful in giving significance to our further observations. The local glaciers of Disco were found to present sloping borders, after the usual style of southern glaciers. It would appear that this mode of termination is the dominant habit of the glacial border in southern Greenland, but I was not permitted to make observations which justify me in asserting this, and the writings of others do not seem to be sufficiently specific on this point to warrant an unqualified affirmation. The glaciers of Disco have much the same limitations in size as the glaciers of southern alpine regions, and this may possibly give occasion for the inference that the element of magnitude is a controlling one in determining the marginal habit of a glacier. In view of this possible appeal to magnitude as an element of interpretation, it is fortunate that we have been able to study glaciers of like dimensions in high latitudes. It may be safely inferred, therefore, that the differences in the verticality of the glacial margin, which we have found so pronounced, and in the basal stratification (if this difference really exists) are not functions of magnitude.

In like manner it is of some importance to know whether the differences in the magnitude of the glaciers of the northern field, when compared with each other, are correlated with any impor-

tant variation in the mode of their deployment. If it shall appear that there are no essential differences between the action of small ice-caps and large ones, an important gain to interpretational methods will have been realized; for, if magnitude does not constitute an important source of difference in mode of action in high latitudes, it probably does not in low latitudes, where only small glaciers exist and comparisons in magnitude are impossible beyond the narrowest limits. In so far as a comparison of the foregoing small ice-caps and their dependencies with the great ice-cap and its dependencies, yet to be described, contributes to the adjudication of the element of magnitude as a factor in glaciation it subserves a function to which few contributions have been possible heretofore.

It will of course not be overlooked that there is an important distinction between the small glaciers which we have just studied and the small alpine glaciers that have been the chief subjects of study in southern latitudes. The glaciers of Redcliff peninsula all radiate from a common ice-cap gathered upon a plateau of moderate elevation. The glaciers of like magnitude of southern latitudes hang on mountain slopes or nestle in mountain valleys. The nearest approach to an ice-cap in these regions is found in the snow fields that mantle the mountain cols. The rugged environment of the alpine glaciers has given to them a burden of superficial detritus which very much obscures their basal features and has imposed a constraint in deployment which very much distorts their normal evolution. From these restricting conditions the glaciers of the Redcliff peninsula are almost wholly free.

A special point of comparison between small and large icefields, of supreme importance in its bearings on the interpretation of the drift of the Ice Age, is the mode of introduction and transportation of rock débris. The small fields show us these phenomena as executed in short distances; the great fields, in long distances. The diameter of the Redcliff peninsula is not more than fifteen miles; the diameter of the great ice-cap is 700 miles, a ratio of about one to fifty. None of the material

borne out by the radiating glaciers of the Redcliff peninsula can be supposed to have been carried more than six or eight miles. Some of that borne out by the great inland sheet may have been carried three or four hundred miles.

If, in the descriptions and illustrations that follow, it shall be found that the interlamination of débris in the base of the great ice-cap is of the same nature and degree as that of the small ice-caps we have just studied, it will seem to be a safe inference that this intrusion of débris has narrow limitations in its development and is not at all proportional to the magnitude of the ice body with which it is connected. The point is one of fundamental importance, for it has a decisive bearing on the radical question whether the ratios of free to loaded ice which are found to obtain in the small glaciers can be applied to the great ones that are now extinct. If, for instance, it is found that a glacier which is no more than six or eight miles in length is well inset with débris to the height of fifty or sixty, or even one hundred feet, from its base, it might be inferred — indeed it has been inferred — that a glacier 300 or 400 miles in length might be filled to a proportional height, *i. e.*, to 2500 or 3000 or even 5000 feet. If such a law of ratios holds true, we shall find the glacial lobes and border of the main ice-cap exhibiting an interlamination and a burden of débris of a truly magnificent order.

The purpose of this discussion, at this point, is to quicken observation on the illustrations of the great ice-cap, and of its lobes and tongues, to which we now turn.

The Tuktoo glacier.— The general form and relations of the Tuktoo glacier may be best apprehended by reference to the maps opposite pp. 198 and 669 in preceding articles. It will there be seen that it is simply a lobe of the main ice-cap descending from the north to the lowland which constitutes the neck of the Redcliff peninsula. Its movement is directly opposite to that of the Krakokta glacier last described, which descends the north slope of the Redcliff plateau. These two glaciers come into direct conflict and form the most interesting joint terminal

moraine already described in connection with the Krakokta glacier (p. 836). In view of the considerations above noted, the

FIG. 60.—View of the south side of the eastern lobe of the Tuktoo glacier seen from a point on the lower slope of the Sentinel nunatak, looking northeasterly. The smooth, nearly vertical wall of the glacier is seen in the foreground with the crevasses running from left to right with an inclination forward. Crossing these in the upper part of the glacier may be seen numerous lines running from left to right obliquely upwards and backwards, and curving toward the glacial axis in measurable conformity to the configuration of the ice. At the right hand in the foreground is seen the terminal moraine mantling a base of ice, and also a portion of one of the lakelets mentioned in the text. Beyond this moraine is seen the Bowdoin glacier which is separated from the Tuktoo glacier by a depression and by the moraine just mentioned. The eminence in the background at the left is the Sierra nunatak. The eminence in the distant center is the Sugar Loaf which stands on the border of the inland ice field. The lobe obscurely seen on the right is the Mirror glacier. The moraine from which Mr. Peary took his departure on his last trip across the great ice field may be seen obscurely, perhaps, at the right of the illustration, nearly opposite the Sugar Loaf.

reader is invited to turn back to the figure on the page cited and compare at a single glance a glacial lobe of the great ice-cap and a glacial lobe of a very small ice-cap. It will be difficult to

find any essential difference between the structure, the débris burden, or the mode of action of the two glaciers. The moraine is very symmetrical and shows no preponderance of action on either side. The right-hand slope is made up of gray crystalline rock contributed by the lobe of the great ice-sheet, and the left-hand slope is made up of red sandstone contributed by the lobe of the little ice-sheet. The work of each is perfectly declared and is singularly balanced.

If from this point of junction and conflict we turn to the right and follow the border of the Tuktoo glacier, we shall find it holding aloof in a measure from the Sentinel nunatak whose base it skirts. A vertical wall faces the nunatak throughout the entire arc skirted by the glacier. At no point does the ice press hard against the sides of the mountain. On the west angle it rises somewhat on the foot slope but does not close up the fossa between the ice and the mountain.

Our first illustration (Fig. 60) is taken from the base of the nunatak looking northeasterly obliquely across the south face of the eastern lobe of the glacier. It will be seen that the vertical wall possesses the same features of interlamination of débris in the basal part, and of freedom from débris in the upper part, which has so generally characterized the glaciers previously described. The face here is the smoothest and most strictly vertical which I observed in Greenland, and the amount of interlaminated débris is notably fine in grain and small in amount. The absence of a moraine or talus slope at the base (except at the extremity) will be noted. The interlamination of detritus reaches to the height of about seventy-five feet above the base. Although an offshoot of the great ice-cap, it is to be noted that the débris does not rise higher than in the glaciers from the small Redcliff ice-cap. The amount of the included débris happens to be here somewhat less than that in most of them.

In describing the upper Blase Dale glacier of the island of Disco (p. 785, Vol. II) note was made of numerous fracture lines traversing lateral portions of the glacial surface in a direction at variance with, indeed transverse to, the normal course of

crevasses in such a position. A similar system of fracture lines is observable on the side of the Tuktoo glacier facing the Sentinel nunatak. The general nature and course of these may be made out from an inspection of Fig. 60, but the details are bet-

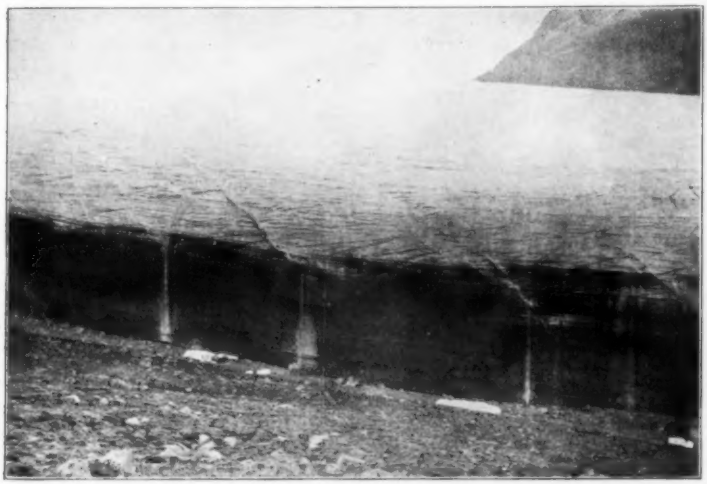

FIG. 61.—A nearer view of the south side of the eastern lobe of the Tuktoo glacier from a photograph by Professor Libbey, showing the verticality of the wall, the absence of a moraine at the base, the crevassing in a moderate degree, having the direction usually taken on the side of a glacier, and, particularly, the non-gaping crevices, running transverse to the crevasses.

ter seen in Fig. 61. In the upper part of the glacier it will be observed that there are numerous oblique fracture lines starting within the dark band which represents the vertical wall of the glacier and running obliquely backward and upward, curving toward the axis of the glacier. It will be seen that these cross the layers of the ice, which are shown by light and dark banding on the vertical side and by parallel ridgings on the upper surface of the glacier. The normal system of crevassing may be seen imperfectly by the gaping fissures on the side of the glacier at the left in Fig. 60. They are also indicated by the

streams that issue on the face of the glacier in the center of the figure. These follow the crevasses until they reach the face of the glacier, when they descend it vertically. (It may be remarked in passing that the whiteness of the track of these little streams as they descend the side of the glacier indicates the relative purity of the ice. The blackened, unwashed surface shows the extent to which the fine débris, when freed by slow melting, covers the surface and invites an illusive impression of its amount.) Fig. 61, from a larger photograph taken by Professor Libbey, shows more satisfactorily both the normal, gaping crevasses and these unopened crevices, and displays at once their differences in nature and in direction. By inspection of this figure it will be seen that these crevices extend to depths quite comparable to those reached by the crevasses, though they are individually less persistent. It will be observed that they usually terminate at a bedding line or at a fellow crevice and that they very much resemble the jointing of certain tilted rock beds. In some instances faulting appears to be indicated.

As remarked in the case of the upper Blase Dale glacier, the stress or tension which caused these crevices was not of such a nature as to require the gaping of the crevice after it was formed. In this respect, as well as in their direction, they differ from normal crevasses. It will perhaps be best to reserve a discussion of the cause and significance of the phenomenon until the remaining glaciers are described and the general subject of interpretations and inferences is taken up.

The two photographs show imperfectly a horizontal lining or ridging of the retreating surface of the glacier above the vertical face. These lines really represent a series of small terraces, the vertical faces of which rise a foot or so in height and the upper faces of which range up to a dozen feet in width. These terraces are really the obliquely outcropping edges of the glacial strata and are developed into the terrace form by differential melting of the ice, much as steps in stratified rock are developed by differential erosion. Their attitude is due to the upward curving of the layers of ice as they come to the surface, in accordance with

the habit of the glaciers of the region. These little terraces were so pronounced that one instinctively follows them in walking upon the upper surface of the glacier if his course lies at all coincident with them.

FIG. 62.—View of the terminal face of the Tuktoo glacier at the southeastern curve of the eastern lobe, showing the projection of the upper layers over the lower and the attendant phenomena.

An inspection of the base of the glacier as shown in Fig. 61 gives emphasis to the remark already made respecting the smallness of the débris in the ice and the absence of a lateral moraine. Following the face to the right, however, it will be seen that at a point where the border curves about to form the terminal face of the glacier, as shown in Fig. 60, there is a notable accumulation of débris in the form of a terminal moraine. This, however, is deceptively large, as the mass of the ridge is composed of ice concealed beneath a veneering of rock rubbish.

This terminal deposit extends around the extremity of the glacier to the Sierra nunatak which is seen in the background of the illustration, at the left.

The wall of the glacier, which in the foreground of the illus-

FIG. 63.—Another view of the terminal face of the Tuktoo glacier at the southeastern curve of the eastern lobe, showing a more marked projection of the upper layers over the lower with the fluting of the under-side of the layers.

tration is so smooth and vertical, becomes irregular and overhanging at the extremity. This irregularity consists essentially in the projection of the upper layers over the lower. This overprojection reaches an extent of twelve or fifteen feet and takes on the aspects which are so well illustrated in the reproduction of photographs 62 and 63 as to leave little need for verbal description. The projecting portions consist of thick beds of nearly clear ice separated by seams of dirty ice. The phenom-

ena naturally raise the question whether the projection of the upper layers is due to actual overthrust of the upper layers or merely to the more rapid melting of the lower layers, or to a combination of the two. There is no question but that the dirty layers absorb the solar heat with more facility than the cleaner ice and are melting backward more rapidly, and that some of the irregularities which the vertical faces of this and other glaciers present are due to this differential melting. There is, on the other hand, little room for doubt that the upper layers of the glacier move faster than the lower ones. This is in accord with the generally accepted doctrine that the upper portion of a glacier moves faster than the lower, a doctrine based upon observation as well as theory. It is, however, an open question whether the differential motion is localized along the planes which separate the layers, or whether it is distributed through the mass. It is not advisable to enter at length upon the discussion of the question here, but these very striking phenomena merit special study with reference to it. It will be observed that the undersides of the projecting layers are distinctly fluted. This might easily be interpreted as a demonstration in itself of the movement of the upper layers over bowlder-shod under layers, resulting in the grooving of the over-running masses. It appears clear, however, that to some extent at least the fashioning of these flutings in the form in which they are now seen is due to the action of water descending the face of the glacier and flowing backward on the under side of the projecting layers. This does not, however, dismiss the hypothesis that the initiation of the fluting was due to differential motion between the layers. The fact that the débris has been carried in between the layers is in itself very significant respecting the hypothesis of one layer sliding over another. But this differential motion might have been confined to the point where the débris was carried in and may not be taking place in this terminal part of the ice. So this class of evidence, though it is pertinent to the general question of a shearing motion between the layers, is not altogether unequivocal in its application here.

Between the Tuktoo glacier and the Bowdoin glacier, which lies immediately east of it and runs transverse to this part of it, there is a valley in which has accumulated morainic material from both. The amount of this, however, is rather unexpectedly small when we consider the size of the two glaciers and the activity of the latter. Under this débris there is much ice and probably the two glaciers are in actual contact below it. Between the two glaciers and the adjacent nunataks there are two small lakelets of triangular outline, one lying on the right-hand side of the Tuktoo glacier, hemmed in between the two glaciers and the Sentinel nunatak, and the other on the left hand, between the two glaciers and the Sierra nunatak.

The vicinity of the nunataks afforded an opportunity to find a minimum measure of the height to which the ice formerly rose. Drift and glacial erosion were observed on the summit of the Sentinel nunatak up to a height of about 1600 feet. The extreme summit was much broken and riven and gave uncertain evidence whether it had been completely submerged or not.

T. C. CHAMBERLIN.

STUDIES FOR STUDENTS.

DEFORMATION OF ROCKS.—IV. CLEAVAGE AND FISSILITY (*continued*), JOINTS, FAULTS, AUTOCLASTIC ROCKS.

RELATIONS OF CLEAVAGE AND FISSILITY TO OTHER STRUCTURES.

RELATIONS OF CLEAVAGE AND FISSILITY TO BEDDING.

WHERE a rock series is composed of layers of different lithological character, and is in the zone of combined fracture and flowage, the deformation includes the development both of cleavage by normal plastic flow and of fissility in the planes of shearing, in both homogeneous and heterogeneous rocks, and perhaps of all gradations between the two. The beds in the heterogeneous rock may be each approximately homogeneous. There is necessary rearrangement within the beds as well as readjustment between them. Therefore the rearrangement within the beds, in so far as it is not affected by the readjustment between the beds, will tend to produce cross cleavage and cross fissility, while the readjustment between the beds will mainly be by parallel slipping, and will tend to produce parallel cleavage and parallel fissility (Fig. 10, p. 478).

In passing from the limbs of the folds toward the crests or troughs, parallel readjustment becomes less and less important, and normal plastic flow or fracture along the shearing planes becomes more and more important. At the arches and troughs the thrust for a given bed are approximately equal, in opposite directions, and when deeply enough buried its entire thickness is under compression. The direction of least resistance is vertical. Therefore the conditions which here prevail are those of

the formation of cross cleavage and cross fissility. It follows that in heterogeneous rock strata, parallel structures may prevail on the limbs of the fold, and cross structures on the crests and in the troughs. At intervening places may be found all the complex effects of the interaction of the two (Fig. 7). In many cases where there is almost perfect accordance of primary and secondary structures on the limbs, and the rocks are so crystalline that the two cannot readily be discriminated, at the crests and troughs both structures may readily be seen intersecting each other.

FIG. 7 (reprinted from p. 470).— Parallel fissility on the limbs of the folds and cross fissility on the anticlines, and gradations between the two. After Heim.

The deformation is mainly by folding, but on the anticlines, where the material is partly relieved from stress, the deformation is partly by the multiple minor slips of fissility.

Formations are but divisions of rock masses greater than beds which are roughly homogeneous. In each formation, considered as a whole, cross secondary structures will usually be produced, while at the contacts between the formations, where major readjustment is sure to occur, nearly parallel structures may be found. In the discussion of each separately it has been seen that in the cases of extreme folding the relations between the different secondary structures and bedding are nearly the same, and therefore that cleavage and fissility developed under each of the laws will merge together, and both be approximately parallel to the reduplicated beds. They are all brought into nearly parallel positions, just as are pebbles in the folding process. In order that this should be done, it is plain that there must be such extreme rearrangement of the rock material that it could not inaptly be compared with kneading.

In rock masses in which the alternating layers of different strength are not beds, the principles of the development of cleavage and fissility are the same as in the heterogeneous

bedded rocks. The different layers may be due to secondary structures. They may be due to the flowage of igneous material along primary or secondary planes of weakness, or to secondary water-deposited impregnations along such planes. They may be due to heterogeneous injections. In all of these cases, as in any other, the stronger beds will to a certain extent control the movements. The accommodations will occur along the layers when folded, and there will be a tendency for cleavage and fissility to develop parallel to them.

The more unequal the layers in thickness and strength, the more likely is the major accommodation to take place parallel to them, and thus produce cleavage and fissility which nearly accord with them. In proportion as the rocks approach massive ones, the law of cross structures prevails, but in a minor way readjustments along the laminæ may occur, and these laminæ still retain their integrity. In rocks as they occur in the field both tendencies are always present in all the parts, from the minute laminæ to the largest masses. Sometimes the first is predominant, sometimes the second. If the lamination is not strongly marked the first tendency will control, although the lesser layers or laminæ of unequal strength may in a minor way control the movements.

Ordinary shale is a representative of rocks having minute layers of slightly different strength. Usually the average of the cleavage or fissility distinctly cuts the beds. The material yields to thrust by flowage or fault slips combined with minute puckerings. If the process be continued far enough the individual layers are folded upon themselves in a large number of parallel folds, nearly at right angles to, or inclined to, their original positions. Therefore, while cleavage does nearly correspond with the original beds, the particles have been so much deformed and rearranged and the layers have been so far readjusted as to make the term bedding scarcely applicable.

As has been seen (p. 474), beds are particularly likely to largely control the direction of cleavage or fissility if the folds are monoclinal and overturned. In such folds the major dif-

ferential movements are along the longer limbs. Therefore the cleavage develops in a corresponding direction, being nearly parallel to the bedding on one limb of each fold and cutting across the bedding on the other, steeply inclined or overturned limb. As the area of outcrop of the steeper limbs is much less than that of the more gently inclined ones, the fact that the cleavage cuts the bedding on one side of each fold is very likely to be overlooked. As a result of the greater mashing thus developing cleavage or fissility the longer limbs of the folds are thinned more than the shorter limbs.

If for any cause cleavage be parallel to the bedding planes, as these are apt to be sh aring planes in the zone of fracture, the predominant fissility would be likely to be parallel to the bedding. The other direction of fissility would be transverse to the bedding, and might have a wider spacing. The first might be called fissility and the second joints.

In another case, after a cross cleavage has developed and the rocks have passed into the zone of fracture, the stresses may result in the development of fissility along two sets of shearing planes, one of them being controlled in direction by the cleavage, the other by the bedding. The more regular parting, parallel to the cleavage, might be called fissility, and the less regular parting, parallel to the bedding, might be called either fissility or joints, depending upon its closeness. Whether the intersecting planes of fissility are at right angles to each other would depend upon the inclination of the cleavage and the bedding.

In regions of complex folding it is difficult to make accurate general statements of the relations of cleavage and fissility to bedding. However, as a result of the action of the various forces, a bed has a definite strike and dip, and the cleavage and fissility have definite relations to these. As there are rapid variations in strike and dip in regions of complex folding, it is to be expected that there will be variations in the directions and character of cleavage and fissility. Certain of the specific relations of bedding and secondary structures in regions of complex folding have already been considered (pp. 347–349).

RELATIONS OF CLEAVAGE AND FISSILITY TO THRUST FAULTS.

Between cleavage and fissility developed along the longer limbs of folds and thrust faults, which accord in dip with the beds on the longer limbs, there is only a difference in the magnitude and frequency of the movements.

When fissility or cleavage develops there are many slightly or infinitesimally separated movements of small degree. When a thrust fault develops there is a single major movement. It is believed that the relief is more likely to be by faulting at little depth, and at greater depth is more likely to be by the development of cleavage, and often, secondary to it, fissility, or more rarely by the development of fissility directly. The passage of cleavage by gradation into minute overthrust faults is beautifully illustrated a short distance northwest of Blowing Rock, N. C. Where fissility is not developed throughout the rock mass it may occur adjacent to thrust faults, due to the shearing adjacent to the thrust planes. Rock masses deformed by thrust faults and showing fissility adjacent to the faults will have zones of fissility which alternate with others in which this structure is absent. Where fissility varies in perfection of development in alternating zones, but is present throughout the rock mass, it implies that the relative movements were concentrated to a certain extent along definite zones, but that movement everywhere occurred. It is plain that *shearing developing cleavage and fault slips along planes of fissility accomplish the same mass deformation as do thrust faults*, only it is averaged throughout the rocks instead of being largely concentrated at certain planes.

Differential movements similar to those described in the above paragraph may occur along a lamellar structure in any kind of a rock, sedimentary or igneous.

By differential movements, such as are above described, enormous masses of material may move forward long distances The top of the mass, having the advantage of all the differential movements below, will travel the farthest (Figs. 5 and 6, p. 468). The base will move the least. From this mass at some later time

mountains may be carved. As each stratum grinds over the one below it the former presses against the latter with all the weight of the superincumbent material. Under such circumstances it is no wonder that a coarse-grained, massive granite may be transformed into an evenly laminated schist. In the zone of fracture the schist, developed in the zone of flow, may become fissile, and the slickensided, wavy folia may be thinner than paper. It is by folding combined with differential movement that the abnormal folds described on a previous page are produced.

The cleavage or fissility so frequently present upon the flanks of anticlinal core-rocks in great mountain ranges may be explained by similar movements. In the section on the analysis of folds it has been shown that much readjustment must occur upon the limbs of folds. The flanks of an anticlinal mountain core are such limbs, and hence the development of cleavage or fissility parallel to the central massif. In passing toward the center of the core we approach nearer the crown of the anticline, and penetrate to a greater depth; hence less readjustment is necessary, and therefore the secondary structures are less prominent.

RELATIONS OF CLEAVAGE AND FISSILITY TO THICKNESS OF STRATA.

Without reference to the origin of secondary structures, or any evidence upon this point, bedding and secondary structures are often spoken of as corresponding. Even reputable textbooks make such statements. This confusion is most unfortunate for two reasons. (1) It often leads to great overestimates of the thickness of strata, the real thickness of the beds being supposed to be the apparent thickness as observed across the secondary structure, where, as shown by the foregoing analysis, the same bed may be repeated many times. (2) The mistake is likely to give erroneous ideas of structure. If the primary and secondary structures are thought to correspond, the whole breadth of a slate or schist may be regarded as a bed of enormous thickness, and this will lead to the preparation of sections in which the mass is represented as extending to a great depth, where it may be comparatively superficial. (Fig. 12.)

The assumption that bedding and secondary structures correspond is still less justifiable when no remaining evidence of bedding is found. If only cleavage or fissility be found and the relations of the beds with other beds are not such as to give the direction of stratification, no inference in reference to this point should be drawn.

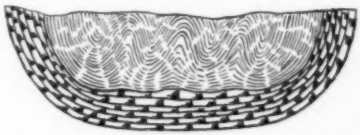

FIG. 12. — Closely plicated shale underlain by bed of limestone.

It is apparent that attempts to estimate the real thickness of cleaved or fissile beds must take into account two difficulties: (1) The same bed may be folded on itself many times, and these folds must be followed, or at least some estimate must be made of the thickness of the beds which would be present if the minute plications could be straightened. (2) In the complex folding of the beds there is readjustment, mashing and consequent lengthening of the layers upon the limbs, and they are, therefore, on the average, thinner than originally. So far as such thinning occurs, it compensates for the reduplication of the beds, but it is believed that this compensation is far short of full correction. To fully overcome these difficulties is often impossible, and estimates of the thickness of closely folded, cleaved, and fissile beds, even when all the difficulties are wholly understood and allowances made, are usually only approximate.

DEVELOPMENT OF CLEAVAGE BY OTHER CAUSES THAN THRUST.

Thus far I have considered cleavage developed in connection with and dependent upon orogenic movements. It is probable that this structure develops in other ways. It may be that deeply buried beds may become cleavable with the structure parallel to bedding, where superincumbent pressure, cementation, and metasomatic changes are the predominant forces.

Such deep-seated rocks, if below the level of no lateral stress, are in the zone of great vertical compressive stress and circumferential tension. They would, therefore, be shortened vertically. If under the stress of gravity movement goes far enough, this would develop a cleavage parallel to the surface. Such cleavage in sedimentary rocks would be parallel cleavage and would emphasize the bedded structure originally formed. Just below the level of no lateral stress it is probable that the circumferential dilation would be slight, but would increase with depth. Whatever its amount, it is a real cause so far as it goes.

It is not asserted that rocks in which cleavage may thus develop reach the surface by subsequent denudation, but perfectly crystalline schistose rocks in which the cleavage corresponds exactly with the bedding, and which are but gently folded, suggests that such may have been the conditions under which the structure formed, and if the estimates given for the depth of the level of no lateral stress, from two to eight miles,[1] are correct, it is certain that rocks which have been below this level in some regions have subsequently reached the surface by denudation. It is generally believed that the Laurentian and Adirondack areas are regions of profound erosion, and here are found excellent illustrations of gently folded cleavable schists, the structures of which apparently correspond with original bedding. The above explanations may be applicable to these regions. This method of the development of cleavage parallel to the surface of the earth below the level of no lateral stress is also applicable to igneous rocks.

Laccolitic or batholitic intrusives might promote this process by giving great pressure parallel to the bedding and by heating percolating waters, thus rendering them more active. In the Adirondacks the cleavage of the schists and the periphery of the batholite of gabbro have in some places a parallel arrangement, and the intrusion of the igneous rock has probably been one of the causes of the metamorphism and the parallel relations

[1] Origin of Mountain Ranges, by JOSEPH LE CONTE, JOUR. OF GEOL., Vol. I, 1893, pp. 566–568. JAMES D. DANA, Manual of Geology, 4th ed., 1895, pp. 384, 385.

obtaining between schistosity and bedding. Readjustment between the beds, as explained on a previous page, may also have assisted in the process.

In a third case, a great boss of intrusive igneous rock may cause the secondary structure to be everywhere parallel to it, without reference to the direction of previous structures. This case probably differs but little from that of direct thrust, but the direction of thrust gradually varies through 360° in circumscribing the mass, being at all times radial. The material pushed aside obeys at each point the law of normal plastic flow, just as in ordinary orographic movements. The new minerals develop with their shortest diameters in the direction of thrust. Old minerals are mashed into similar forms in parallel positions. The heat of the igneous rocks furnishes hot solutions which help to transform the old minerals. As the direction of the thrust varies gradually around the intrusive, the secondary structures follow, and therefore form a zone around the intrusive, the layers of which may be compared to those of an onion (see pp. 454–456).

The process may be complete, and old structures, such as bedding, previous cleavage, or previous fissility, may be wholly destroyed. In other cases traces of these structures may still be found. Where the earlier structures are wholly obliterated near the intrusive, they may appear gradually in passing away from it. Thus in the same rock mass several structures may occur. The mica-schists about the intrusive granite core of the Black Hills are an excellent illustration of this case.

MODIFICATIONS OF SECONDARY STRUCTURES.

The partings of fissility may be concentrated here and sparse there. In the cracks between the laminæ a new mineral or minerals may be deposited from water solutions, and the secondary zones of greatest fissility would then have a composition different from that of those which are less fissile. Moreover, the parted laminæ and the minute layers of infiltrated material may be of different composition. This would give a minute

alternation of layers of different characters. Such a major and minor alternation of different materials may simulate the appearance of bedding to a remarkable degree. If such structures are taken for bedding, mistakes in structural work will follow.

Where fissility is developed in an igneous rock, secondary impregnations may occur between the laminæ, just as above described. Thus there would be formed a rock with alternating layers of different mineral character, no part of which is sedimentary, and yet which closely simulates a sedimentary structure. If either the sedimentary or the igneous rock which has become fissile be intruded by igneous materials, these might follow the cracks in a minute way, and thus again produce a structure which is very similar to bedding.

In the above cases both the process of water impregnations and that of igneous injections tend to cement the rock. If the process be complete the crevices of the rock may be entirely healed. The once fissile rock will then have lost its fissility. It may, however, have the property of cleavage parallel to the banding. Such a cleavable rock may give no evidence that it was once fissile. From the foregoing I conclude that *banded rocks may owe their structure to fissility and secondary impregnations or injections, or both, and the bands may or may not accord with an original structure.*

After a first secondary structure has developed, later movements may produce a new cleavage or fissility, which cuts this earlier structure at right or oblique angles, or the new force may be so intense as to produce a structure which wholly destroys the earlier structure. Usually, in order that a new structure may be produced, it is necessary that the new force shall vary considerably in direction from the first, so that it cannot be decomposed into two components, one parallel to the old structure and one at right angles to it. To this fact is doubtless due the comparative frequency of cleavage and fissility in several directions in the same rock mass; but while the secondary structure is ordinarily in a single direction, an exposure or even a hand

specimen may show the original bedded structure and secondary structures in two or more different directions. In fact, as has been shown, a single simple orogenic movement may produce both cross and parallel secondary structures, and the cross fissility may be in two directions.

While it is rare to find more than two or three structures in a rock, theoretically there is no limit to the numbers which might be produced; but practically, as has been seen, new movements usually emphasize old structures, or else produce new structures, which tend to obliterate the old structures. *However, in a thoroughly crystalline rock, if there be two or three structures, it is not safe to assume that the oldest and most intensely plicated one is bedding.* This has been done frequently in the case of the crystalline schists and gneisses by those who would not regard cleavage or foliation, if but a single structure existed, as evidence of bedding. The older the structure the greater is the probability that it is really bedding, but the fact that it is the earliest structure which now exists in the rock cannot be regarded as conclusive, for it may have been produced by an early orogenic movement which simultaneously obliterated bedding.

After a secondary structure has developed in a formation it may be folded into anticlines and synclines. In order to be thus folded it is usually necessary that the secondary structures be not steeply inclined. As indicated on a previous page, where such a structure develops in a horizontal position it may correspond with bedding, but also it had been seen that cleavage or fissility may form with slightly inclined planes of movement which cut diagonally across the bedding. Such a cleavage or fissility may be emphasized by secondary impregnations and injections, in which case it simulates bedding to a remarkable degree. In either of the above cases a careless observer would be almost certain to regard the structures as bedding.

The number and severity of orogenic movements may in many places have been so great along old ranges that it is not strange that it is impossible to differentiate or separate the various formations upon a structural basis. The beds have

been kneaded again and again by the orogenic forces; cleavage, fissility, and band banding may have developed in different directions; earlier structures may have been destroyed by later transformations; until it is no longer possible to determine the position of original bedding.

APPLICATION TO CERTAIN REGIONS.

In many mountainous regions in which there has been profound erosion, illustrations of nearly all of the foregoing principles may be found. Attention may be directed to one or two of the more important.

It has already been pointed out (pp. 337–338) that in the Appalachian and New England crystalline areas the main direction of active stress was probably from the southeast toward the northwest. At any rate, the couple composed of force and resistance was such as to make the higher strata move toward northwest as compared with the lower strata, or to make the lower strata move to the southeast as compared with the upper strata. As a consequence of this, the folds of that area have axial planes which have a very general tendency to dip to the southeast. If the force be supposed to have been directed toward the northwest, and to have been equal for different depths throughout the thickness of the rocks now exposed at the surface, the cleavage which developed in the normal planes would dip to the southeast. This would have been due to two causes: First, the direction of normal pressure, compounded of thrust and of gravity, would have been northwest and downward, which would, therefore, have given a southeasterly dip to the cleavage. Also, because of increasing resistance and probably lessening thrust with increasing depth, the force would have caused the higher strata to have moved differentially over the lower ones. There would, therefore, have been a shearing motion, the higher strata moving upward and northwestward as compared with the lower. As a result of this shearing and of shortening, the old and new mineral particles would lie with their longer diameters in southeasterly-dipping planes and give a cleavage in that direc-

tion. The conjunction of these two forces would have given a flatter dip than would follow from either one of them alone.

While the above statement is true on the average, the case is complicated because of the differential movements in individual folds. The cleavage for a given section is in a single direction to the southeast only when the folds have a decided monoclinal attitude, and this is especially marked where the folds are all overturned. Even here, however, the cleavage tends to be flatter upon the limbs in normal positions than on the overturned limbs. In the areas in which the folds approach a symmetrical character, cleavage with northwest dips is found on the northwest limbs of the folds. The explanation of these phenomena is given on pages 461–475.

While there is a general tendency in this region for a southeasterly-dipping cleavage, there are great variations in the steepness of the dip in different beds in the same locality, and variations in the average steepness in different localities. The variation in steepness in the same area is explained by the fact that the differential movement between the strata was largely concentrated in the weaker beds, so that the cleavage in them is flatter than in the more resistant beds. The general variation in the dip of cleavage in passing from area to area may be explained by a difference in the character of the rocks, by a difference in the intensity of the forces at varying depths, or by a difference in the depth of burying. The particular average inclination for a given area depends upon a combination of all these variables.

With given forces, if the rocks are more resistant in one area than in another, there is less shearing motion, and therefore steeper cleavage in the former than in the latter. Other things being equal, if the forces are more intense near the surface than at a greater depth, the shearing motion is greater at higher horizons, and hence the cleavage is flatter in passing toward the surface. A given force would produce less and less shearing motion with increasing depth, because of the increased friction, and hence the cleavage may be flatter in passing toward the surface, just as in the foregoing case.

For any given area, after cleavage developed, as denudation progressed the zone of flowage passed upward into the zone of fracture. It is clear that the cleavage planes already developed were then probably shearing planes, and this was true even if the horizontal thrust was the same and in the same direction in the zone of fracture that it was in the zone of flowage, for the direction of greatest normal pressure is composed of thrust and gravity, and therefore at a great depth is steeply inclined to the horizon, whereas in the zone of fracture, gravity being less important, the direction of greatest normal pressure is less steeply inclined, and therefore normal planes in the zone of cleavage become shearing planes in the zone of fracture. In the development of fissility along the cleavage planes there were slight differential movements between the laminæ, and hence was formed the very extensive fault-slip cleavage so well known in the Appalachians. It is believed that the more regular and widespread fissility is thus secondary to cleavage, but it is recognized that fissility or joints formed in other directions, and that in the outer zone, which was never in the zone of flowage, original fissility or jointing only was developed.

As pointed out by Willis, in the western area of little altered rocks in the southern Appalachians the deformation was mainly by faulting; in the corresponding area in the northern Appalachians the deformation was mainly by folding. At intermediate areas the deformation was by faulting and folding. Parallel to the fault-planes fissility developed to some extent in the area of fracture, and dipping in the same direction as the monoclinal folds cleavage developed in the area of folding. In an intermediate area the deformation was by major faulting, by minor fault-slips along fissility, by the pure shortening and shearing motion producing cleavage, and by monoclinal folds, all combined. The interactions of these are more fully described in other places (see pp. 595–598, 620–622).

Returning to the crystalline area, in the cracks and crevices between the fissile laminæ mineral impregnation from water solution occurred at many places, and thus gave the rocks a

parallel banding, as described by Hobbs in the Searls quarry. In other districts parallel injections of igneous rocks occurred, and here the metamorphosed schists are wedded together along the fissile planes by igneous material. Such are the conditions in southeastern New York, and especially on northern Manhattan Island in the vicinity of New Rochelle.

As shown in other places (pp. 600–603), there may be all gradations between aqueous impregnations, through aqueo-igneous deposits, to true igneous injections. Usually the original rock differs in chemical and mineral composition from the impregnations or injections. The process gives a distinctly banded structure, which has often been mistaken for metamorphosed original sedimentary layers. Also the chemical composition may be so changed, if the amount of secondary material is large, as to make it impossible to tell from its chemical analysis whether the original rock is aqueous or igneous.

If the parallel mineral impregnation, or the parallel igneous injection, or the two together, had been general throughout the Appalachian semicrystalline and crystalline areas, we should have a vast series of crystalline schists with parallel banding, the bands generally dipping to the southeast, and these layers might be mistaken for beds, and thus lead to estimates of enormous thickness for the series, when in reality the original sedimentary beds were of no unusual thickness. This error has not been made for much of the Appalachian region because in most areas the metamorphism has not been so extreme but that the cleavage is detected intersecting the bedding at the sharp turns of the layers on the crests of anticlines and in the troughs of synclines. Had the metamorphism gone as far throughout the region as it has in certain places, the bedding could not be discovered, and there would be now no means of tracing out the different steps of the process of modification. But in the Appalachian and New England regions the steps of the process of the development of cleavage and fissility, the stages of the parallel impregnation and injection, and all degrees of metamorphism may be observed, so that in some of the regions of most

extreme change the genesis of the rocks and their structures are determined with reasonable certainty.

In the eastern region the areas in which the sedimentary rocks have gone through the process above described are more extensive than those of igneous rocks, but all steps of the process have also affected extensive areas of igneous rocks. Examples of the latter are the pre-Cambrian granitoid gneiss of the Green Mountains, and, more extensive than this, the great areas of ancient plutonic and volcanic rocks of the Blue Ridge and Piedmont Plateau.

It is believed that the regularly banded and laminated Laurentian gneisses which have an isoclinal dip over great areas in Canada, along the Madison Canyon in southwestern Montana, and in other regions, may be explained by the same processes completely carried out as applicable to the Appalachians. It is not asserted whether the original rocks in these regions were igneous or aqueous. The general drift of opinion in recent years is in favor of the former origin.

RELATIONS OF CLEAVAGE AND FISSILITY TO STRATIGRAPHY.

Cleavage or fissility may be developed in one set of beds and not in another set of beds in the same set of formations. Secondary structures develop readily in a shale, less readily in a fine grit, still less readily in a limestone, and perhaps with the least readiness in a quartzose sandstone, quartzite, or conglomerate. As a consequence of this, a shale between beds of limestone may take on a thoroughly cleaved or fissile character, the cleavage stopping abruptly at the beds of the limestone. The same is true of layers of shale between beds of grit, or sandstone, or quartzite, or conglomerate. In general, *in the strata constituting a formation, cleavage may develop in the less rigid beds and be absent or imperfect in the more rigid beds.* In such cases it has sometimes been assumed that the lower bed was deposited and cleavage or fissility developed in it before the superior bed was formed, the fact that a secondary structure was not so ready to develop in the upper bed being ignored.

In determining unconformities the use of cleavage and fissility follows the same principles as given on pages 351–353 in reference to folding. To safely infer that there is a structural break between series it is necessary to show that cleavage and fissility would be as likely to develop in the superior formations as in the inferior ones. It is further necessary that the two series be in actual superposition, not in adjacent lateral positions.

It has been seen that in proportion as cleavage and fissility develop, the original structures of the rock are obliterated. Where there is apparently complete destruction of the bedding for parts of folds, at areas of less movement, as, for instance, the crests of anticlines and the troughs of synclines, the beds may still be recognized, and thus the relations between the primary and secondary structures be determined.

JOINTS.

ORIGIN OF JOINTS.

Various causes have been assigned for joints, of which the more important are tension, torsion, earthquake shocks, and shearing. It is believed that joints may be classified into *tension joints* and *compression joints*. The first are ordinarily in the normal planes, the second are in the shearing planes.

Tension joints.—Tension is often due to the contraction caused by cooling or by desiccation. It is well known that the peculiar columnar jointing of igneous rocks is due to the contraction and consequent tension caused by cooling, and the mud cracks of sedimentary rocks are due to the contraction and consequent tension caused by desiccation. However, it is probable that neither cooling nor desiccation is important in the production of systematic sets of joints in the sedimentary rocks.

It has already been seen that when rocks are simply folded and not too deeply buried the convex halves of the anticlines and synclines are subjected to simple tension (pp. 205–208, Fig. 1). If the tension goes beyond the limit of elasticity, radial cracks will be formed which strike parallel with the rocks.

Joints of this class are at right angles to the tensile force. This class of joints is beautifully illustrated in the sharp folds of the graywackes of the Hiwassee river, in the Ocoee series. If the folded rock has planes of weakness of any kind, due either to a primary or secondary structure, the fracture due to the tensile stress may be controlled by these, and thus deviate from the normal planes.[1]

Joints produced by tensile stress may have smooth or rough surfaces, depending upon the character and strength of the rock. If it is a weakly cemented sandstone, the fracture, as pointed out by Becker, is around the grains. If, however, it is a strong, tolerably homogeneous graywacke, quartzite, or limestone, or similar rock, the fractures may be clear-cut and sharp. After joints due to tensile stress have formed, subsequent movements may press the surfaces together, or may fault the strata in a minor or major way, and thus produce slickensided surfaces.

It has been seen in the discussion of folds that, instead of being simple, and, therefore, in a horizontal attitude, they usually have a pitch; or, in other words, the rocks are folded in a complex manner. In such regions there may be tensile stresses in two directions at right angles to each other, thus producing two intersecting sets of joints. One of these sets, that roughly parallel to the more conspicuous folds, would be called strike joints, while the other set of joints, parallel to the transverse folding, would be called dip joints. Both sets would intersect the bedding nearly at right angles. The fact that two sets of joints in these positions so frequently accord in direction with the strike and dip is strong evidence that many joints are produced by the tensile stress of folding on the stretched half of

[1] BECKER states that "Tension will not produce joints or cleavages. The theory of the distribution of tension cracks is the explanation of columnar structure" (this JOURNAL, Vol. IV, footnote, p. 444). Where equal contraction occurs in all directions as the result of cooling or desiccation, this is well known to produce columnar forms, but where there is tension in only a single direction, this may produce one set of approximately parallel joints. Tension at a later time in a direction at a large angle to this may produce another set of joints. Or, finally, unequal tension at the same time in two directions nearly at right angles to each other may produce two regular sets of intersecting joints.

the mass folded. If the folds are nearly horizontal — that is, if the force was mainly in a single direction — the strike joints may be strongly developed and few dip joints produced. If, on the other hand, the folds are important in both directions, the strike and dip joints will both be important.

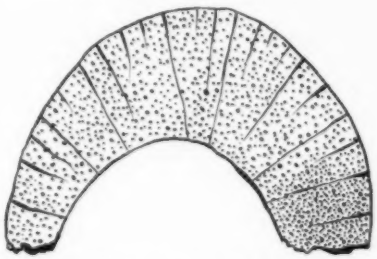

FIG. 13.— Radial cracks due to tension in sharply flexed stratum.

Daubrée has shown that if a brittle plate fractures when it is subjected to torsion beyond the limit of elasticity, a double set of parallel fractures nearly at right angles to each other are produced.[1] The forces which produce complex folding deform the strata, where not too deeply buried, in two rectangular directions by tensile stress; or, in other words, they are subject to torsion. It therefore appears that Daubrée's explanation of joints by torsion is but another statement of the production of joints by complex folding normal to the two principal directions of tensile stress.

A question for investigation is the extent of the area over which joints and faults run in rectangular directions. In the case of a large and strongly pitching fold, the force of torsion may produce rupture in different directions upon different parts of the folds. Upon the flank of the pitching fold, at a proper point, strike joints and dip joints may be formed, striking halfway between the ordinary strike joints and faults, and dip joints and faults at the crests and troughs, and between the two there would be all gradations.

[1] Géologie expérimentale, par A. DAUBRÉE, pp. 306–314, Paris, 1879.

Crosby has recently suggested[1] that when torsion has nearly, but not quite, reached the limit of elasticity in rocks, an earthquake shock may act as the trigger which sets the process in motion, and he thus combines this cause with torsion in explaining joints. Crosby also emphasized the fact that a plate when subjected to torsion does not crack along a single plane of fracture, the weakest plane, but that many parallel fractures are produced. He applies this fact to rock beds, and suggests that the fracture must first occur at some one plane, that of the greatest stress or least strength in the distorted belt. The shock of the fracture, added to the force of torsion, goes beyond the ultimate strength of the beds at the next weakest plane, thus fracturing them and producing another joint, and so on, until the complicated fracturing actually obtained in the glass plate is paralleled by the rocks. He thus makes the rupture of the first joint itself serve the purpose of a secondary shock, and this rupture a third shock, and so on, producing a set of joints in rapid succession over an extended area. Finally a place is reached where the rock has not been sufficiently distorted for the shock of the last fracture to carry the stress beyond the breaking strength. This theory is as applicable to simple tension as to torsion. In the above it appears that Crosby has overlooked the fact that he has not explained the first earthquake shock. The statement might be amended as follows: The first fracture occurs because the steadily acting orogenic forces finally go beyond the ultimate strength of the deformed beds. When rupture takes place, this gives the first shock. This initial shock carries the stress beyond the ultimate strength of the next weakest planes, and so on.

Compression joints.— Daubrée[2] and Becker[3] show that joints may be produced by compression. In this case there will be jointing in two planes when the rocks are simply folded, and,

[1] The origin of parallel and intersecting joints, by W. O. Crosby, Am. Geol., Vol. XII, 1893, pp. 368–375.

[2] Géologie expérimentale, par A. Daubrée, pp. 315–322, Paris, 1879.

[3] George F. Becker: Finite homogeneous strain, flow, and rupture of rocks. Bull. Geol. Soc. Am., Vol. IV, pp. 41–75, 1893. The torsional theory of joints. Trans. Am. Inst. Min. Engineers, ol. XXIV, pp. 130–138, 1894.

according to Becker, there may be jointing in three or four planes when they are complexly folded, one of these being normal to tensile stress and the others in shearing planes. However, where there are more than two sets of joints at right angles to each other, it is probable that in many cases these have been caused by successive orogenic movements, the second being in a different direction from the first. Becker has explained that minor faulting is a common phenomenon of compression joints.

When the folding is simple, both sets of joints developing in the shearing planes, although dipping in different directions, would accord in their outcrop with strike, and might therefore be regarded as strike joints. When the folding is complex it may be that different sets of shearing planes would correspond to strike joints and dip joints, but upon this point further observation is needed.

In the Knox dolomite of east Tennessee the formation of joints along both tensile and shearing planes is beautifully illustrated at numerous localities. Commonly the joints produced by tensile forces are nearly perpendicular to the bedding. Two sets of joints, equally inclined to the bedding and making obtuse angles with each other, are clearly in the shearing planes.

The attitudes of joints produced by shearing and their relations to bedding would be identical with fissility, as described on pages 593–597. Whether the structure be called fissility or joints would depend upon their number. If numerous and close together the structure would be called fissility; if fewer and farther apart, jointing. The same compression might produce fissility along one set of shearing planes, and joints along another. If the above be true, it is clear that there are all gradations between joints and fissility. It has been suggested that the term "fissility" might perhaps be wisely restricted to the cases where the structure is secondary to a previous one, such as cleavage or bedding, and that the term "joint" should be used to cover fractures along independent shearing planes.

In thus explaining many joints as the result of the same forces which produce folds, it is not meant to imply that there

are not joints of other origins, but merely that the master joints, which run in different directions approximately parallel to the strike and dip, may be thus explained, and these are the joints which are the most useful in determining the structural relations of different series.

ZONE AFFECTED BY JOINTS.

Joints, implying as they do openings in the rocks, are necessarily confined to the outer zone of fracture and the middle zone of fracture and flowage. In the first zone they are of more importance and probably more regular than in the second. In the deeper zone of rock-welding no joints can develop. In rocks once buried to this depth, which subsequently reached the surface by erosion, joints may be formed; for in approaching the surface they passed from the zone of flowage, through the zone of fracture and flowage, into the zone of fracture.

RELATIONS OF JOINTS TO STRATIGRAPHY.

If there is a greater number of sets of joints in an inferior formation or formations than in a superior formation or formations, the two divisions being of such lithological character as to be equally likely to take on jointing, this argues that there may be discordance between the two sets, for it is probable that the lower set of formations, which has the more complicated jointing, was subjected to orogenic movements which produced a part of these fractures, before the upper series was deposited. Comstock has applied this as the determining criterion in separating three supposed series of rocks in the Llano district of Texas. The lower series of formations is said to have three sets of pronounced joints running in definite directions, while the middle series has only two sets of joints running in definite directions, these two being common with two of the three in the lower series, and the upper series has a single set of joints running in a definite direction, this system being common to both the inferior series. Comstock's inference is that the system of joints in the lowest series not found in the upper two series was produced

before the upper two series were deposited, and that the two sets of joints found in the lower series, one of them also affecting the middle series, and both absent in the upper series, were present before the latter series was deposited. That is, the lower series was subjected to three orogenic movements, the middle series to two, and the upper series to one. Considering that two or more sets of joints may be developed by a single orogenic movement, it would seem that such a conclusion should be supported by other criteria.

FAULTS.

ORIGIN OF FAULTS.

Faults differ from other rock fractures, in that there is important dislocation along the fractures and often also they are far more extensive. Like joints, faults may be classified into *tension faults* and *compression faults*, the first forming in the normal planes and the second in the shearing planes. Faults are, however, usually defined as normal and reverse. A *normal fault* is one in which the overhanging side descends in reference to the other, while in the reverse fault the overhanging side ascends in reference to the other. Another term applied to reverse faults is *thrust faults*, implying that tangential thurst is the controlling factor. As equivalent to normal fault may be placed the *gravity fault*, implying that gravity is the predominant force.

In the case of the normal fault the overhanging side has a smaller base than the other. Consequently by force of gravity it descends, as compared with the other side. In all cases both of normal and reverse faults, gravity is a never-ceasing force. At first explained by Le Conte,[1] the principle of the inclined plane thus applies to these two forces, the hade of the fault giving the inclination of the plane. Where the hade is greater than 45° if the forces of gravity and tangential thrust are equal the fault is normal, because gravity controls the movement (Fig. 14). If, on the other hand, the hade is less than 45°, tangential thrust is

[1] On the origin of normal faults, and of the structure of the Basin region. JOSEPH LE CONTE. Am. Jour. Sci. (3), Vol. XXXVIII, 1889, pp. 257–263.

the predominant force, and the fault is a reverse one (Fig. 15). As the hade becomes steep, gravity has greater and greater relative power, and if the hade is very steep, gravity may be able to overcome the tangential thrust, even if the latter is several times as great as the former. So, also, if the hade is flat, tangential thrust even much weaker than gravity may overcome it and pro-

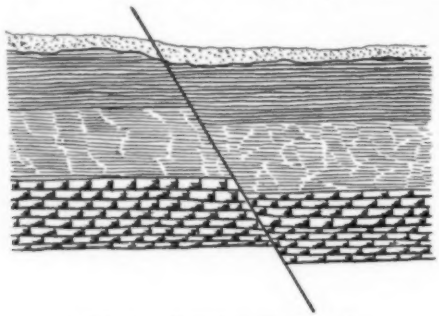

FIG. 14.—Normal or gravity fault.

duce a reverse fault. This is one reason why, as a rule, normal or gravity faults have steep hades, while reverse or tangential faults have flat hades.

There is, however, another reason. Since tension faults form in the normal planes, they are usually steeply inclined or nearly vertical. But the very idea of tension faults implies that there is no thrust. Hence, gravity has its full effect, and the overhanging side goes down with reference to the other side. It does not follow, therefore, that all gravity faults are tension faults, although this may be the case. Compression faults form in the shearing planes, and they are therefore likely to be much inclined to the vertical. In order that rupture shall occur the thrust must be great, and hence compression faults are usually, and perhaps always, thrust faults.

Perhaps it would be well to classify faults as gravity faults and thrust faults rather than normal and reverse faults, and thus give them names which refer them to the predominant causes. For the present this classification is preferable to the classifica-

tion into tension faults and compression faults; for it is possible, though hardly probable, that an inclined fracture may result from compression, and after a time thrust lessen in amount, so that gravity controls the final differential movement.

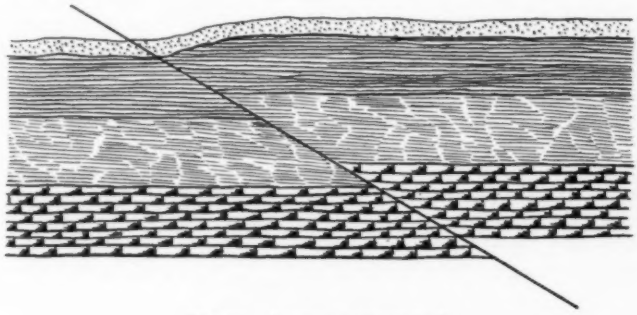

FIG. 15.—Reverse or thrust fault.

RELATIONS OF FAULTS TO EXPANSION AND CONTRACTION.

Gravity faults result in the dilation of the part of the crust affected by them (Fig. 14). Thrust faults result in the contraction of the part of the crust affected by them (Fig. 15). In a region in which many parallel faults occur, all of the same character, the dilation, or contraction may be a considerable percentage of the breadth of the area disturbed. Since the amount of dilation or contraction with a given vertical movement increases as the hades become flat, and since thrust faults have flatter hades on the average than gravity faults, the shortening of the crust in a region of thrust faults is usually greater than the elongation in another region in which gravity faults are about equally abundant and in which the vertical displacements are the same.

RELATIONS OF FAULTS TO STRIKE AND DIP.

While there is great variability in the direction of faults, due to exceptional causes, faults are more parallel to the strikes and to the dips, other things being equal, than in other directions, so that faults are sometimes spoken of as strike faults and dip faults.

Since a fault may be no more than a displaced joint, this relation is easily explained in the same manner as in the case of joints. (See pp. 610–612).

RELATIONS OF FOLDS TO THRUST FAULTS.

It has been long recognized that thrust faults are often related to overfolds. If the strata are in the zone of combined fracture and flowage, the overfolds may be broken along the reversed limbs and the arch limbs be thrust over the trough limbs. In a region of overfolds and thrust faults, if it could be determined whether the differential movements are such as to carry the material moved toward the surface or away from the surface, it could be decided whether such folds and faults should be called overthrusts or underthrusts.[1] But the differential movements, the forms of inclined and overturned folds, and the character of the thrusts are identical, whether a given bed above be considered as moving forward and upward as compared with the layer below, or be considered as moving forward and downward as compared with the layer above. In Fig. 16, if the force be considered as applied at A, it would be called an overthrust fault; if the force be considered as applied at B, it would be called an underthrust fault; and yet the phenomena are identical. The movements must be such that the material goes in the direction of relief, and it is probable that this is more often toward the surface of the earth (see pp. 338, 339) rather than deeper within the earth. It is probable that in certain cases thrust has been transmitted by a strong formation or series and pushed under other strata. This is particularly likely to occur where the lower strata are weaker or where the material in advance of the active strata transmitting the force has been already raised into folds, and thus partly escapes the pressure. (See pp. 316–319, and Fig. 6.)

As explained by Willis, in regions which are but lightly loaded the forces producing thrust faults may result in clean-cut

[1] The term underthrust is taken from PROFESSOR E. A. SMITH. Am. Jour. Sci., 3d series, Vol. XLV, 1893, pp. 305, 306; see also this JOURNAL, Vol. IV, p. 339.

fractures, with scarcely any bowing of the layers of the rocks along the shear planes (see Figs. 4 and 6 on p. 468, and pp. 596–598). In passing to the greater depths the load is greater, and the layers, instead of all having the full movements of the clean-cut thrust faults, adjacent to the fault planes may be found to be in sharp overfolds in opposite directions upon opposite sides

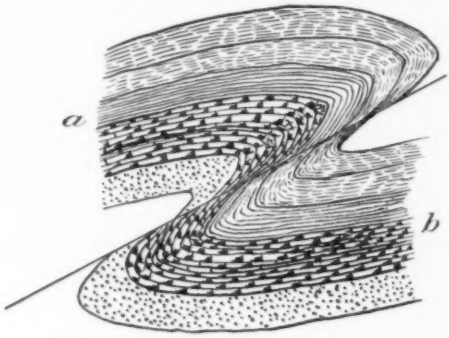

FIG. 16.—Fold passing into fault.

of the faults (Fig. 16). Where the load is still greater these folds are of increased importance. Under still greater load the rocks may be first bent into an overfold, with little faulting, and finally at a greater depth the deformation may occur altogether by overfolding. It is therefore clear that in the same mountain mass there may be all gradations between clean-cut thrust faults and overfolds without faults. The transition may be longitudinal, as in the case of the Appalachians, where thrust faults which occur in the extreme southeast are gradually replaced by overfolds to the northwest. Also the transition may be transverse. In the latter case, if erosion cuts the strata to different depths after such a region was deformed, the overfolds may be found in the central parts of the mountain mass, the transition phases upon the immediate areas, and the thrust faults without overfolds upon the outer flanks of the mountains.

Rocks at a certain depth, and therefore under a definite load,

may be deformed first by folding and afterwards by faulting. Suppose a rock is deeply buried, but not so deeply as to cause the superincumbent load to equal its ultimate strength. Suppose the differential stress for a given stratum under these conditions to surpass the elastic limit, but not to reach the ultimate strength of the bed. It will then be deformed by folding, but during the process shearing occurs on the limbs, and as a result the bed is thinned, and finally the stress may surpass the ultimate strength of the rock, which will then be fractured and perhaps faulted. The same result may be reached if before a stratum or formation is thinned the differential stress increases so as to go beyond the ultimate strength of the rock. It follows from this that deformation by folding followed by faulting is normal for a considerable zone, for when the mountain-making forces for a given region first begin their work it is to be supposed that the differential stress is moderate. As the stress increases in amount so as to exceed the elastic limit the layers would begin to be folded, and fracture would occur as soon as the differential stress reached the ultimate strength of a given layer, provided the rock was not in the deep-seated zone of flowage.

It has been seen (p. 597) that accompanying thrust-faulting fissility may develop parallel to the faults, and accompanying overfolding cleavage may develop which dips in the same direction as the axial planes of the folds. In an area intermediate between the zone of fracture and the zone of flowage, this being at successive times under the conditions of flowage and of fracture, there may be overfolding and cleavage combined with thrust faults and fissility. In passing from a faulted to a folded area, as has been noted, first there may be fissility along the thrust faults, then the strata may be slightly overfolded and tucked under along the faults, this undertucking becoming more and more prominent and fissility at the same time being replaced by cleavage, and finally we may have overfolds with cleavage, with or without faulting. Each of the different phases of the steps of change may occur on a large or small scale. In

some places in an intermediate area a dozen little overfolds with fault slips may be seen upon a single hand specimen. Hence I conclude that *the average deformation of a region may be the same whether it be by a few great faults with little or no fissility, by more frequent lesser faults with or without fissility, by faults and overfolds with or without both cleavage and fissility, or by folding with or without faults and cleavage;* also that *there is every gradation between faulting and fissility, and probably every gradation between faulting and cleavage.*

ZONE AFFECTED BY FAULTS.

A fault may vary in magnitude from a fraction of an inch to many thousands of feet. A fault, like a joint, is limited in horizontal as well as vertical extent. It cannot be assumed to extend very far beyond where observed. A fault of an inch may die out within a few inches, both laterally and vertically; a fault of a hundred feet within a few hundred feet; a fault of five thousand feet within a few miles. In following a fault longitudinally the throw may be found to become less and less until it is zero, just as a bunch of paper may be torn for a part of its length and the different parts of the torn ends be differently displaced. But while faults may thus die out within short distances, they may have remarkable persistence, both in direction and in length. This does not necessarily imply that they have great persistence in depth, for just as a fold has a tendency to die out, as explained (pp. 210, 211), a fault may also die out below, and sometimes also above. In the latter case the fault usually occurs in a stratum or a formation which is brittle as compared with the overlying rocks. Because of the more plastic character of the higher strata the deformation there occurs by folding. *Probably most faults at sufficient depth pass into flexures, and deeper down these flexures may die out.* As already explained, when a bed is deformed under little weight the strain necessarily causes fracture, and the readjustment is largely by faulting along the fractures. When all the conditions are the same, except that there is such load that as a whole the rocks are in

the zone of flowage, the necessary deformation is accomplished by folding. In regions of close folds it is probable that before the superincumbent beds were removed by erosion many of the latter were faulted instead of folded, for they were in the zone of fracture and flowage, and in the zone of fracture rather than the zone of flowage.

Possibly the depth at which important faults disappear is in many cases not more than 5000 meters, although the discussion of the depth of earthquake shocks due to faults leads to the conclusion that some faults extend to the depth of a number of miles.

If there are inclined planes of weakness in the deep-seated zone of flowage, the deformation may largely occur by faulting along these planes.[1] Such inclined planes of weakness may be in sedimentary rocks or in igneous rocks. Since masses of intrusive rocks, either in the form of dikes or of bosses, usually have vertical or steeply inclined exteriors, faulting is particularly likely to occur at the contacts of igneous rocks with one another, or at the contacts of igneous with sedimentary rocks. It has already been explained that such deep-seated faults would differ in no way from the differential movements resulting in cleavage or fissility, except that the movements are mainly confined to narrow zones. This results in great displacement at the fault zones and little displacement in the areas between the faults. In such supposed deep-seated faulting it is to be remembered that the displacement takes place without crevice or joint. At any given movement the rock is to be regarded as welded together. The different parts simply shear over one another along the plane of greatest weakness.

RELATIONS OF FAULTS TO STRATIGRAPHY.

Faults may be used to discriminate between series in precisely the same way as joints, and the criterion has far greater weight. If an inferior set of formations has a more

[1] The Mechanics of Appalachian Structure, by BAILEY WILLIS. Thirteenth Ann Rept., U. S. Geol. Surv., pp. 217–274, 1893. Especially Pls. XCV and XCVI.

complicated faulting than an upper series which lithologically is equally likely to be faulted, this is strong evidence that the lower set of formations was faulted before the upper set of formations was deposited. Faults are frequently not easy to demonstrate or to trace out. Hence this criterion for discriminating between series is not so valuable upon the whole as are the more conspicuous and readily discovered phenomena of folds, cleavage, fissility, and joints, but if the conditions are favorable for tracing out the faults of a region, the information thus furnished may give positive evidence as to structural breaks between series.

GENERAL.

In the foregoing pages folds, cleavage, fissility, joints, and faults are regarded as the conjoint products of thrust and gravity. Similar forces acting upon heterogeneous rocks under various conditions produce diverse phenomena. Thus several classes of phenomena which are often treated as independent and unconnected are genetically connected. A fault may accord in inclination with any of these structures. Between faults and joints, fissility, or cleavage there are all gradations. When there is a marked displacement along a break it is called a fault. Whether a given minor displacement is thus named often depends upon the point of view. Wherever there is fissility there is slipping or faulting, using this term in its exact sense. Usually minor displacements are not called faults unless they occur across the beds or other structures. A displacement across a prior structure of such magnitude as to be called a fault might be ignored if it occurred along the structure. Folding and cleavage belong normally to the zone of flowing; fissility, joints, and faults belong normally in the zone of fracture. In the zone of combined flowage and fracture all the structures occur together in a complex manner, the particular combination of phenomena depending upon the relative thickness, strength, and brittleness of the rock beds concerned.

AUTOCLASTIC ROCKS.

ORIGIN OF AUTOCLASTIC ROCKS.

When rocks are folded by strong orogenic forces, and they are not so heavily loaded as to render them plastic, they are frequently broken into fragments, and "*autoclastic*"[1] rocks are produced. The autoclastic rocks which readily show their origin may be called *dynamic breccias*, and those which resemble ordinary conglomerates may be called *pseudo-conglomerates*. Brittle rocks are the most likely to become autoclastic; hence it is that cherts, quartzites, cherty limestones, graywackes, and rather siliceous slates are some of the kinds which most frequently present the phenomena described. The movements of the broken fragments over one another in many cases so thoroughly round them that they have the appearance of being waterworn, and the matrix between the larger fragments may consist almost wholly of well-rounded fragments of a similar character. For instance, in a semi-indurated quartzite the larger complex fragments may be well rounded by their mutual friction while the matrix may consist of the simple original waterworn grains which are rent apart. In another case the original rock may have consisted of beds of mud interlaminated with thin beds of grit. By consolidation and cementation these beds may have been transformed to alternating shale and graywacke. The shale is plastic under slight load; under the same load the graywacke is brittle. When such a set of beds is deformed the shale yields largely by flow and the graywacke by fracture. The beds of graywacke are broken into fragments of varying sizes, which are ground over one another, and thus are rounded. At the same time the shale flows and fills the spaces between the fragments. Also slaty cleavage may be developed. As a result, a pseudo-slate-conglomerate is produced, having a slate matrix and pebbles of graywacke, which, so far as its own characters are concerned, could not be discriminated by anyone

[1] Structural geology of Steep Rock Lake, Ontario, H. L. SMYTH, Am. Jour. Sci., 3d ser., Vol. XLII, p. 331.

from a true conglomerate. Fortunately, in most cases it is possible to find transition phases between such a rock and one in which the process has not gone so far, and thus one is enabled to determine that the rock is autoclastic.

ZONE OF AUTOCLASTIC ROCKS.

The zone in which autoclastic rocks may be produced is confined to the outer 10,000 meters of the earth's crust, and the formation of widespread autoclastic rock is probably limited to the outer 5000 meters. At a depth greater than the larger number the pressure in all directions exceeds the crushing strength of any rock, and therefore if it were possible for crevices to form such as are necessary to produce brecciation they would be almost immediately closed by flowage. Consequently, at great depths it is to be supposed that no crevices form in the rocks as the result of dynamic movements, and therefore that no breccias are produced.

From the foregoing it follows that autoclastic rocks may develop whether the formations concerned are homogeneous or heterogeneous. Also that they may develop whether the beds are all within the zone of fracture for them or whether they are in the zone of fracture for a part of them, and in the zone of flowage for the other part. In the first case dynamic breccias are likely to form. In the second case only the stronger rocks are broken, the fragments being buried in the members which flowed, and pseudo-conglomerates are frequently formed.

RELATIONS OF AUTOCLASTIC ROCKS TO BASAL CONGLOMERATES.

Since it is possible that pseudo-conglomerates may be mistaken for true basal conglomerates, the criteria which discriminate the two are of great importance.

(1) An autoclastic rock must derive its material mainly from the adjacent formations. If, for instance, it is produced from interstratified layers of limestone and quartzite, it will contain only limestone and quartzite detritus, and the fragments will be mainly from the more brittle formation. Further, an

autoclastic rock may have a part of its material from the superior formation as well as from the inferior. However, in some cases the brecciated layer may itself have been conglomeratic, although not a basal conglomerate, and thus some material from extraneous sources will be found. But in most instances the material is of local origin. In true basal conglomerates, on the other hand, while the material is very frequently derived in large measure from the immediately subjacent formations, they also usually contain a small proportion of material from various foreign sources, and do not contain any material from the overlying formations, as may the autoclastic rocks.

(2) In an autoclastic rock, if the pebbles are closely examined they will in many cases be found to be less rounded than in a true basal conglomerate. If the belts of brecciation be followed for some distance a considerable variation will frequently be found in this respect, fragments being here well rounded and there very imperfectly rounded. The well-rounded fragments are concentrated, as are also the angular fragments. A basal conglomerate, on the other hand, has a considerable uniformity in the degree of the rounding of its pebbles in passing along the same horizon, but at the same place the large fragments may be angular and the small ones well rounded. In a basal conglomerate very near to the underlying formation many of the contained fragments may be angular, but in an extreme case the fragments of a basal conglomerate are upon the average usually not so angular as those of an autoclastic rock.

(3) In many cases the interstices of an autoclastic rock are filled with material of a vein-like character, whereas in a basal conglomerate the filling material is largely finer detritus. But sometimes, as in the case mentioned of a semi-indurated quartzite, the filling material of an autoclastic rock may be water-worn grains of sand, which have been separated by dynamic action, and are therefore indistinguishable from the ordinary matrix of a true conglomerate.

(4) In most instances a bed of autoclastic rock, if followed, may be traced into an ordinary brecciated or partly brecciated

form. A basal conglomerate, on the other hand, if followed along the strike and dip, may change its character, but it will be a gradual change into the ordinary mechanical sediments, whereas an autoclastic rock is likely to have very sudden variations in character.

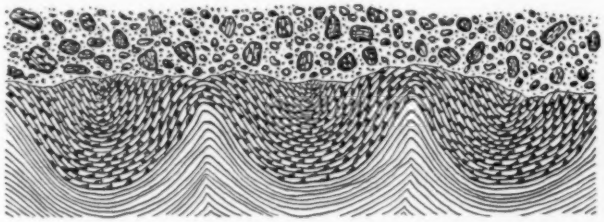

FIG. 17.—Chert breccia, an autoclastic rock resting upon truncated minor folds of limestone.

Using all of the above criteria, it is difficult in some cases to discriminate between an autoclastic rock and a true conglomerate. Usually, however, if an area be studied sufficiently long, and if the relations be examined closely a true judgment may be reached.

Autoclastic rocks are not likely to develop from shales and limestones, but if near enough to the surface even these rocks may become brecciated. As a consequence of orogenic movements, in the zone of combined fracture and flowage, where the alternate layers are thick, the shales and limestones may flow and the cherts and quartzites become brecciated. The brecciated and nonbrecciated layers, under these circumstances, may not become mingled to any considerable degree. Thus we may have a set of autoclastic rocks interstratified with layers which show no sign of brecciation. It may be that the plastic layers, as a result of the stress, may be minutely corrugated. The movement of the broken particles in the rigid layers against the crests and troughs of the folds may have truncated them. We might then have pseudo-conglomerates resting upon folded truncated layers (Fig. 17), and it might be concluded that there

is a structural break between the two, the inference being that one formation was folded and truncated before the overlying clastic formation was deposited upon it. This occurs in the Marquette district of Michigan.

Another case is as follows: A lower shale or grit may be overlain conformably by a sandstone. By cementation these formations may become indurated; the grit into graywacke, and the sandstone into quartzite. After this an orogenic movement may develop cross cleavage or cross fissility in the softer, lower formation, the secondary structure abutting against and sharply terminating at the overlying quartzite. The same movement may develop a pseudo-conglomerate in the overlying formation. In the later stages of the process the differential movement may tear off fragments of the lower slate or schist and include them with the broken, harder formation. Such a pseudo-conglomerate simulates to a remarkable degree a basal conglomerate resting unconformably upon an earlier series, in which it might be supposed that the secondary structure was produced before the overlying formation was deposited. Exactly these relations obtain within the Ajibik quartzite formation of the Lower Marquette series, northeast of Palmer. At first it was supposed that the pseudo-conglomerate was basal and marked an unconformity, and it was only after the locality was repeatedly visited and studied in the utmost detail that the true relations between the two formations were discovered.

Similar phenomena may occur between formations different from those above described, in which the inferior formation is weaker than the superior formation.

As another illustration of the great difficulty in sometimes distinguishing between the two, a case in the Adirondacks may be cited in which a thick formation of gneiss is overlain by a bed of crystalline limestone containing interlaminated smaller beds of gneiss. The whole series has been closely folded. The gneiss, as a result of the folding, is closely corrugated, and to a certain extent its upper folds are truncated by the shearing action. The limestone has acted like a fluidal substance, accom-

modating itself easily to its new position, and by recrystallization has taken on a massive character. The thin belts of gneiss within the limestone have been broken to fragments. The fragments in the limestone matrix have ground against one another until they became well rounded. They are disseminated through the limestone. As the layers of gneiss are thicker and more numerous near the base of the limestone, this part of the formation appears as a limestone containing numerous bowlders and smaller fragments of gneiss resting upon a gneiss formation. Thus an unconformable contact was inferred when the area was first examined, but an extended and close examination of the region showed all stages of transition, from the phase of the rock which appeared to be a true conglomerate to that in which the thin layers of gneiss are interstratified with limestone. Similar phenomena have been observed in the Original Laurentian area and in the Marquette district of Michigan.

C. R. Van Hise.

EDITORIAL.

IT IS important to geologists to know to what extent the glacial drift of northern latitudes owes its thickness to the secular decay of the rocks, and also whether we can use, in high latitudes where decomposed rock material has been removed by ice, data collected on the subject of rock decomposition in the tropics where it has not been so disturbed. In the paper by Professor Derby in the present number, he is disposed to take a conservative view of the subject of rock decomposition in Brazil; and Professor Derby's long residence in that country entitles his opinion to much weight.

Our studies of the subject of rock decay in Brazil were begun and carried on under the impression, probably received from the writings of Agassiz, Darwin, and others, that it was extraordinary and the paper on the "Decomposition of Rocks in Brazil" cited by Derby was given as a record of the facts and an attempt to explain them. It is but just to confess, however, that when the results were brought together we were not as much impressed by them as we had expected to be. And the more we see of decay in temperate regions, especially in unglaciated regions of granitoid rocks, the less striking does the decay of rocks in Brazil appear. In California, in Virginia, in the great kaolin pits of St. Yrieux, France, and in the Guadarrama Mountains of Spain we have seen many examples of the decay of granites and gneisses that are very nearly as deep as any we have seen in Brazil.

The unequal decay of rocks, and even its absence, was not overlooked in the article referred to by Derby. Mention should have been made at that place of a letter by Dr. A. R. C. Selwyn, published in the *Geological Magazine* (1877, p. 94) where he calls attention to this unequal decay of rocks in Brazil and Australia as a possible explanation of glacial lake basins in the north.

The possibility of faulting in the Serra do Mar is a question of importance in connection with the subject of rock decomposition in that region, but too little is known of the facts to admit of anything more than speculation on this subject. The region is covered by a dense tangle of forest and undergrowth that render detailed examination extremely difficult, and this difficulty is greatly increased by the decomposition of the rocks and by the lack of artificial exposure that would help to an understanding of the structure.

Derby thinks the whole question is covered by the proposition of Pumpelly that, other things being equal, the depth of rock decay is due to time and to the permeability and solubility of the constituents. Such a statement admits of no question. But the difficulty with such a way of putting it is that it is simply another way of saying that time, permeability, and solubility are elements of rock decay, for, as to other things being equal, they seldom or never are equal, even in the same region, or in the same rocks. It might be as truly said that other things being equal the rate of decay is determined by the color of the rocks, by their dip or by the dip of their surfaces, or even by the direction of the prevailing winds with reference to their dip. The agencies and processes of rock decomposition are complex.

We are of the opinion that a comprehensive knowledge of this subject is to be had in a study, not of road and railway cuts, but of the mineralogical changes to be found in deep mines and tunnels. The susceptibility to alterations of copper and iron sulphides to sulphates, carbonates, oxides, silicates, etc., offer a delicate test of the penetration of the agencies of decomposition. Penrose cites cases of the alteration of such ores to the depths of 600, 1000 and even 1500 feet. (JOUR. GEOL. II, 1894, p. 295.)

J. C. B.

Reviews.

Greenland Ice Fields and Life in the North Atlantic, with a New Discussion of the Causes of the Ice Age. By G. Frederick Wright, D.D., LL.D., F.G.S.A., author of "The Ice Age in North America," etc., and Warren Upham, A.M., F.G.S.A., late of the Geological Survey of New Hampshire, Minnesota, and the United States. New York: D. Appleton & Company, 1896.

The contributions of the two authors of this volume are essentially equal, the one having prepared eight and the other seven of its fifteen chapters. The names of both authors appear duly on the title page as above indicated, but only the name of Wright appears on the cover. The book takes its point of departure from the unfortunate Miranda Expedition which, after a series of minor mishaps, met with a decisive disaster off the harbor of Sukkertoppen in South Greenland on the 9th of August, 1894. The senior author was a member of that expedition and spent two weeks on the coast of southern Greenland. The junior author has never visited Greenland. With this scant basis of personal observation it is obvious that the work is essentially a compilation so far as its main theme is concerned. The only original contributions to the ice fields of Greenland are the brief observations of Professor Wright on the local glaciers back of Sukkertoppen. The designation of the glaciers as local is not the author's. On the contrary, Professor Wright ends an enthusiastic description of the principal one visited by him, near Ikamiut, with this climax: "This was verily a part of the inland ice" (p. 94). As a further enforcement of this conception he introduces a map, here reproduced in part (Fig. 1), which represents a tongue of ice flowing along the mountainous divide between the South Isortok and the Kangerdlugsuatsiak fiords in brave negligence of the obstructing peaks and soliciting fiords. It may be interesting to compare this with the accompanying photographic reproduction of the British Admiralty chart (based on the Danish Government Surveys) of

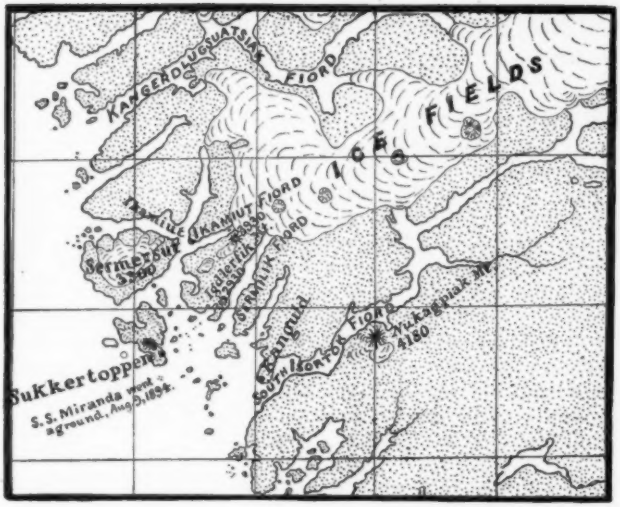

FIG. 1.— Section of the map of the author.

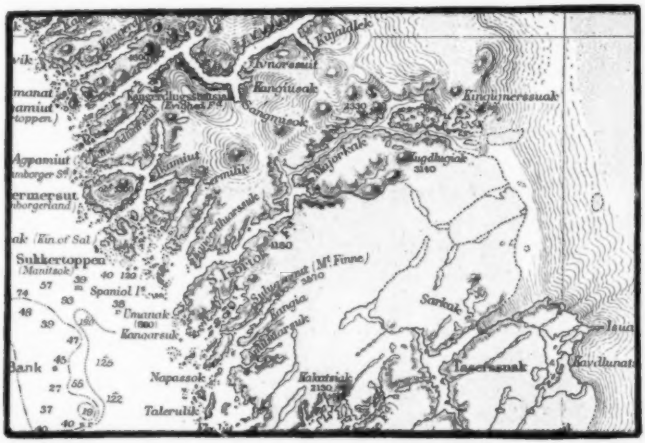

FIG. 2.— Section of the Admiralty Chart.

the same tract (Fig. 2). On it the glaciers appear as the offspring of the snow fields of the mountains that crown the divide and they flow rationally from their local gathering grounds in various directions in due respect to gravitation and the usual habit of glaciers. The glacier near Ikamiut is represented as descending from the snowfield of a neighboring mountain and as finding its source some two-score miles away from the edge of the inland ice which the author nowhere more nearly approached.

Aside from scenic and geographic features, there are two observations of the author that bear on general glaciology: "These glaciers on the south side are all of them thicker near the base of the mountain than in their higher levels. Indeed, they seem to run down like cold tar and to thicken at the base as a stiff semi-fluid would under the action of gravity" (p. 95). "Another phenomenon illustrating the nature of the movement going on in great glaciers was seen here to special advantage. Where the great ice-sheet abutted against the mountain which divided its front into two portions it was pushed up by the momentum of the movement so as to be two or three hundred feet higher at the base of the mountain than it was a mile back. Indeed, a half mile or so back there was a distinct depression in the glacier with the ice higher all around it. It was just such a depression as is made where a current of water is obstructed by some obstacle; the current pushes some distance up the obstruction and then breaks over the sides to go around it; but ice, being much less fluid than water, moves off in larger swells and more gradual curves" (p. 95). A simple computation of the momentum of the glacier and of the ratio of this to basal friction is sufficient to reveal the absurdity of attributing this phenomenon to momentum. There is a special infelicity in citing fluidal action by way of illustration, since it is quite clear that it is the element of *rigidity* in the ice, acted upon by pressure from behind, that produced the upthrust.

Perhaps the observations of Professor Wright on icebergs should be included among the original contributions of the volume to the glacial phenomena of Greenland. Icebergs were encountered — literally in one case — in large numbers and quite unusual dimensions and they are very graphically described. The one with which the Miranda collided is said to have "towered hundreds of feet above us" (p. 6), and another was estimated "to have pinnacles which rose more than 700 feet above the water" (p. 3). In the minds of those

who are familiar with the limited depths of the fiords and bays from which the icebergs issue, these towering dimensions will doubtless awaken skepticism, notwithstanding the appeal made in the latter case to an extended base. Professor Wright contributes some interesting observations on the coast of Labrador, accompanied by excellent views.

The chapters written by Professor Wright relate to the *Ice of the Labrador Current*, *The Coast of Labrador*, *Spitzbergen Ice in Davis Strait*, *Excursions on the Coast of Greenland*, *The Coast in Detail*, *The Eskimos of the North Atlantic*, *Europeans in Greenland*, and the *Summary and Conclusion*.

Mr. Upham contributes the chapters on *The Plants of Greenland*, *The Animals of Greenland*, *Explorations of the Inland Ice of Greenland*, *Comparisons of Present and Pleistocene Ice-sheets*, *Pleistocene Changes of Level around the Basin of the North Atlantic*, *The Causes of the Ice Age*, and the *Stages of the Ice Age in North America and Europe*. These chapters contain a large amount of matter brought together from diverse sources and will prove very serviceable to those who have no convenient access to the original literature, or who lack the time to make use of it. The non-geological part of it we must leave to the botanists and zoölogists. The summary of explorations of the inland ice embraces numerous and extended extracts from the writings of the several investigators of the region, knit together by explanatory matter and accompanied by illustrations from Jensen and Chamberlin and a map prepared by the author.

The chapters which relate to the Pleistocene ice-sheet and the causes and stages of the Ice Age are essentially a reproduction, in a revised form, of the author's recent papers on these subjects in various scientific publications and are so familiar to geologists as not to need special review here. Mr. Upham brings out into sharper definition than before his acceptance of the doctrine of notable ice stages. He defines and maps the Warren, Toronto, Iroquois and St. Lawrence stages in addition to the more generally recognized Kansan, Iowan and Wisconsin stages, and applies the nomenclature of the last group to Europe. It is to be observed, however, that the mapping, if not the discrimination, of the four added stages, is almost wholly hypothetical. Mr. Upham still prefers to interpret these stages as phases of a single period of glaciation. The definite recognition

of distinct stages, however, removes from the advocacy of the doctrine of "unity" the gravest objection which has heretofore lain against it, viz., neglect of important discriminations and confusion of formations diverse in age and nature. The degree of separation of the glacial stages recognized by Mr. Upham finds its maximum illustration in the retreat of the ice after the Kansan stage for a distance of 500 miles and its readvance about 350 miles, an oscillation which, if applied to Greenland, would eliminate and reproduce its ice-sheet.

Mr. Upham still urges the hypothesis of elevation as the chief cause of the Pleistocene glaciation. It seems not a little infelicitous to urge this doctrine in a work on Greenland, since the testimony of that region weighs heavily against the doctrine. At intervals along a thousand miles of the western coast it was observed by the present writer that a notable part of the mountainous border is rugged and angular and betrays no evidence of ever having been overridden by inland ice. A small driftless area was also discovered on the very border of the inland ice on Bowdoin Bay between latitudes 77° and 78° which shows more unequivocally that there has never been a general extension of the Greenland ice-sheet westward much beyond its present outline. The evidence of former elevation is as pronounced in Greenland as in any part of the northern hemisphere. It appears, therefore, that in this land of glaciers *par excellence*, the former elevation of two or three thousand feet or more was not accompanied by any great extension of glaciation, if indeed it was accompanied by any general glaciation at all. It appears, therefore, that the epeirogenic theory is weak on its most radical point — coincidence of elevation with glaciation — in its most promising region. To the writer it seems unfortunate that the public should be so industriously indoctrinated in a theory of the cause of the Ice Age which encounters such serious and seemingly fatal testimony in the very home of glaciation.

T. C. C.

Ice-Work, Present and Past. By T. G. Bonney. International Scientific Series. New York: D. Appleton & Company.

For the past twenty years the author has written chiefly on petrological subjects. Many of his earlier papers, however, dealt with ice and its work, and this book is an expression of the revival of that

earlier interest. He assigns as an especial occasion for adding another to the treatises on glaciology the predisposition of most authors to advocate some particular interpretation of the facts rather than to describe the facts themselves. He has made it his endeavor to follow the example of a judge rather than an advocate. To the extent of maintaining a judicial spirit he seems to have been quite successful. But in assuming to perform the functions of a judge he appears to have overlooked a prerequisite quite as essential as impartiality, viz., an intimate knowledge of the law and the facts in the case. Twenty years of specialization in petrology is scarcely an ideal preparation for donning the judicial ermine in the glacial *cause célèbre*. The inevitable lack of close familiarity with the glacial investigations of recent years is displayed throughout the work. It has led the author to depend upon other compilations, and these not always the best. As a result much of the matter does not come to the reader even at second hand. Haworth and Wright were evidently very serviceable in the preparation of the book. In some notable instances a compiler is quoted as authority instead of the original investigator, even when the original literature is easily accessible and well known. Further currency is given to some things which were doubtful at the outset and which have since passed beyond serious consideration, for example, the alleged benches 1700 feet above the surface of the Great Lakes, and the hypothetical Lake Ohio, based on the hypothetical Cincinnati ice dam. The lack of an intimate command of the subject also appears in the author's inability to adjudicate theories when it is quite possible to do so. This is pointedly illustrated in his summation of the hypotheses respecting the formation of kames and eskers, in which he says: "On the whole, rivers, swollen by melting ice and snow, seem the more probable cause, but it is still open to discussion whether kames and eskers are to be regarded as monuments of sub-glacial torrents or as marking the path of streams which, in the latter part of the glacial epoch, cut their way through expanses of soft and fine material which subsequently have been removed" (p. 168). The latter alternative is wholly beyond seriou consideration, as it is altogether inapplicable to the phenomena.

The work is divided into three sections, Part I, relating to the existing evidence as found in Alpine glaciers and in Arctic and Antarctic ice-sheets: Part II, relating to traces of the glacial epoch, in which lake basins and their relations to glaciers, the parallel roads of

Glen Roy, ice-work in Great Britain and Ireland, and in Europe and other parts of the world constitute the leading themes; and Part III, relating to theoretical questions, especially the temperature of the glacial epoch, its possible causes, and the number of epochs. The discussion of the temperature of the glacial epoch embraces the largest amount of measurably unfamiliar material and is perhaps to be regarded as the most valuable part of the book. The description of alpine and polar glaciers is not brought up to date and is sadly lacking in suitable illustrations, for which abundant material now exists. In the discussion of the traces of the glacial epoch disproportionate attention is given to the excavation of lake basins, to the exclusion of erosive work in other lines quite as important, and the author's impartiality is not as well sustained here as elsewhere. Very much attention is given to the glacial phenomena of Great Britain, and relatively scant attention to that of Europe and America. It is natural that an English writer, presumably having in mind chiefly the English public, should give much prominence to home phenomena, but obviously in a work which takes on so comprehensive a title and is published as a part of an international series, the distribution of attention should be somewhat proportional to the development of the phenomena. In the discussion of the possible causes of the glacial epoch the author's judicial attitude appears to the best advantage. We think he is correct in concluding that "the glacial epoch has not yet received any satisfactory explanation." The literary style of the work is excellent, the language being clear and quite free from rhetorical coloration. The illustrations are not only scant and poor, but the selection is unfortunate in several cases, some of them being unworthy of reproduction.

T. C. C.

General Relations of the Granitic Rocks in the Middle Atlantic Piedmont Plateau, by G. H. WILLIAMS. (Fifteenth Annual Report, U. S. Geol. Surv., pp. 657–684.)

THE Piedmont plateau is classic ground in American geology. Within its limits many of the important problems of American science have been worked out, but by far the larger number of questions which it presents are yet unanswered. It is a region of great complexity. From the holocrystalline, undoubted igneous masses of the eastern border to the unchanged sedimentaries further west there is

every gradation. Dynamic metamorphism, contact phenomena, folds, faults, thrusts, shearing, and foliation are all presented over and over again. The unraveling of the history of such a region must be the result of long and patient detailed work. Only after most elaborate field and laboratory investigations can facts of broad bearing be enunciated.

It was in this region that the late Professor Williams did by far the larger portion of his life's work, and he had a knowledge of it which no other man has ever had. The results of many of his studies have been already published, and so we have his papers on the gabbros and his beautiful map of the Baltimore region. The larger generalizations which only come after many years of study were in many cases not yet completely formulated, and in others, while formulated, were unpublished.

In the present paper we have Professor Williams' views as to the origin of the granites and pegmatites. As an introduction to the former he has summarized the criteria for the recognition of ancient plutonic rocks in highly metamorphosed terraines ; a summary which is most valuable, though marred by the incompleteness of the references. Among other field evidences of the igneous origin of doubtful rock masses are enumerated the presence of radiating apophyses, foreign inclusions, and contact zones. That these may be obscured is recognized, and in the recognition of altered eruptives the author evidently relies largely upon chemical and petrographical evidence. The test formulated by Rosenbusch and depending upon the definite or indefinite character of the chemical composition of the rock has been applied by Professor Williams to certain of the gneisses of the region. Faint traces of structure originally igneous are found in rocks which are quite completely changed. The development of certain minerals is regarded as strongly suggestive of contact metamorphism. The determination of the relative ages of intrusions in such a region must rest largely upon contact phenomena. Often an eruption may prove to be anterior or posterior to some period of strong metamorphism, and hence its relative place in the history of the region may be known. It is by means of such evidence that the origin of the granite masses has been tested. The detailed observations upon granites of the central portion of the state are recorded by Dr. Keyes, and in general it may be stated that with few exceptions the granites of the entire region may be proved to be of igneous

origin. A very interesting table showing the chemical composition of the ancient igneous rocks of Maryland accompanies this paper.

With regard to the pegmatites, evidence is presented for the belief that very many of them are eruptive; though it is not thought that all will be found to have had that origin. The evidence that they are eruptive is based upon the agreement in composition between the granites and the pegmatites, the greater abundance of the latter near granite masses, their independence as regards the character of the rocks they cross, their relations to the adjoining rock, and the fact that as a rule these pegmatites are neither drusy nor symmetrically banded. The fact that in spite of the essential identity between the composition of the pegmatites and the granites there are certain differences, is interpreted as pointing to somewhat different conditions of formation, in which there was a greater activity of the mineralizing agencies.

The author agreed closely with De Beaumont, Lehmann, and Brögger in his conception of the process of the origin of these pegmatites. They are interpreted "as the products of the residual, and therefore most acid, portion of a granite magma highly charged with water and other mineralizing agents, in a state intermediate between fusion and solution, interjected into fissures and there crystallized in very coarse-grained aggregates, not necessarily through any great slowness of this process, but rather in virtue of the aid to crystallization afforded by the abundance of mineralizers present."

H. F. BAIN.

Sketch of the Geology of the San Francisco Peninsula, by ANDREW C. LAWSON. Fifteenth Ann. Rep. U. S. Geol. Surv., pp. 399–476. Pls. V–XII.

THIS paper is a valuable contribution to the literature of the Pacific coast. The area considered lies between the Pacific Ocean and San Francisco Bay, and extends from the Golden Gate southward about twenty-one miles.

The work done reveals seven formations which, in their geological order, are: (1) Crystalline limestone; (2) Montara granite; (3) The Franciscan series; (4) Sandstone of Tejon (?) age; (5) The Monterey series; (6) The Merced series; (7) The Terrace formations.

The Montara granite is exposed along the Pacific shore about one

mile south of Point San Pedro, or about sixteen miles south of the most northern point of the peninsula. At its exposure along the shore line it is overlain by the basal conglomerate of the Franciscan series, but a short distance from shore it becomes the surface rock and covers an elliptical area whose major axis is ten miles, extending in a northwest and southeast direction, and whose minor axis is four miles. That this formation is newer than the crystalline limestone is indicated by the fact that "farther south in the Santa Cruz range, the same granite is found in irruptive contact with pre-existing terranes among which crystalline limestone or marble is prominent," and also by the fact that a mass of marble was found embedded in the granite within the area considered.

The petrographic character of the Montara granite leads to the conclusion that it cooled as a batholite. The mantle, which consisted in part of the crystalline limestone was almost entirely removed before the Franciscan series were deposited, which in turn were removed before the Tejon-like sandstones were laid down.

The Franciscan series occupy the greater part of the peninsula, and are separated by the Merced Valley into a northern and a southern area. Petrographically the series are divided into (1) A basal formation; (2) The San Francisco sandstone; (3) Foraminiferal limestone; (4) Radiolarian cherts; (5) Volcanic rocks. Of these the most important are the San Francisco sandstone and the Radiolarian cherts.

The San Francisco sandstone is that of the early writers. It forms the bulk of the sedimentary rock of the series. Its original color is a greenish or bluish gray, but it easily weathers to a yellowish brown. In the field it presents a massive aspect "due to the thickness of the beds and the obscurity of the bedding planes."

The Foraminiferal limestone is described as having "a fairly constant petrographic character throughout the terrane, although it is found at more than one horizon." It is generally traversed by two sets of veins—calcitic and siliceous. The latter are often parallel to the bedding of the limestone, and may be contemporaneous with it. The limestone itself is thought to be a chemical precipitate.

The Radiolarian cherts are of a dull reddish-brown color, are several hundred feet thick, composed of sheets of chert from one to four inches thick alternating with partings of shale, and occur locally in lens-like masses. Petrographically they occur as true jaspers, as rocks of a flinty or hornstone character, as rocks that are easily scratched

with a knife, and sometimes as quartz rock which resembles vein quartz. They vary from those which are amorphous silica to those which are chiefly holocrystalline aggregates of quartz granules. The mineralogical character of the amorphous silica is doubtful. It is perfectly isotropic, but contains a less amount of water and is harder than opal.

Concerning the origin of the Radiolarian cherts, Professor Lawson advances the theory that they are chemical precipitates from springs, and supports the theory by the fact that they occur locally and in lens-like masses. In working over the field in San Francisco and vicinity, it has seemed to the present writer that these rocks were once widespread. This is indicated by the small fragments of chert almost everywhere found on the surface. Their present local occurrence is not remarkable when it is remembered that they have suffered at least two periods of erosion — that preceding the deposition of the Merced series, and the present one. There is also some evidence of an unconformity between the lower portion of this series and the bed of sandstone which separates it into two parts.

The serpentine of the area occurs with the Franciscan series, and is in three tracts extending from northwest to southeast parallel with the strike of the rocks. One of these tracts is north of the Merced Valley, and two of them south. That on the north side occurs in three large masses which are described as the Presidio laccolite, the Potrero laccolite, and Hunters Point laccolite. These are probably expansions in a dike of serpentine which extends from Fort Point to Hunters Point, a distance of about ten miles. They are in places one and one-half miles wide, and reach a thickness of 500 feet. Both the Presidio mass and the Potrero mass consist of two lenses of serpentine separated by sandstone.

The writer calls attention to the great number of masses of "medium-grained, dark, greenish gray rock" in the serpentine of Potrero and Hunters Point. These have been shown to belong to the hypersthene diabases, and in their more altered forms to the epidiorites, and are thought to be inclusions in the serpentine.

The present writer is not familiar with either of the two serpentine tracts on the south side of Merced Valley, but they are described as in all essentials similar to that on the north side.

Professor Lawson finds nothing from either microscopic study or field observations to support the theory that this serpentine has originated from sandstone, but concludes that "the various conditions

and aspects assumed by the rock are functions of a process of chemical alteration from peridotite or pyroxenite and a mechanical disintegration of the rock thus altered."

The rocks of the Merced series rest unconformably upon the Franciscan series, and occur in two areas, one on either side of Montara Mountain. The series consists chiefly of soft sandstone. There are, however, among the series, hard shell beds firmly cemented, and soft shell beds, uncemented; hard beds of gravel, lignitic beds, and a bed of volcanic ash. The northern of the two areas dips to the northeast, and is exposed along the beach for a distance of 20,000 feet. It is 5800 feet thick, and is the heaviest Pliocene deposit known in North America.

The most marked structural feature of the region consists of two fault blocks, both tilted to the northeast, and designated as the San Bruno block and the Montara block. It is this tilting of the Montara block that gives the Merced series its constant dip to the northeast.

That the San Bruno block is older than the Montara block is proved by the fact that the Merced series has all been removed from the former, as well as by the fact that its topography is more mature than the latter.

Two cycles of erosion are indicated on the San Bruno block — an early one which is manifested only above an altitude of 300 or 400 feet, and a later one which has modified the old topography. The modification of the old topography has been effected in two ways. The first is that due to atmospheric and stream agencies, the second to "destructive and constructive shore action at the various stages of the uplift." The crest of San Bruno Mountain is thought to be due to the same cause which determined the 1200-foot terrace on the higher Montara block; and the 750-foot terrace on San Bruno mountain is doubtless due to the same shore line that formed the 700-foot terrace on the Montara block.

On the Montara block there is only the later cycle of erosion manifested. During this time there were formed the two terraces above mentioned. These are well marked on the northeast slope, and less so on the southwest slope.

The consequent streams on the northeast slope of the Montara block which came into existence on its emergence from the ocean, became superimposed streams on reaching the hard terranes beneath the soft Merced series. Later, as a result of the longitudinal faulting, these

were changed into subsequent streams. As these developed, the superimposed consequent streams became atrophied, leaving only the lower part of the San Mateo Creek. "The remarkably straight valley of Crystal Spring and San Andreas is a magnificent example of a subsequent drainage system extending laterally along a fault in opposite directions normal to the original consequent drainage." Other excellent examples of captured and superimposed streams are mentioned.

Lake Merced, though in a structural valley, is considered a drowned valley of stream erosion. The bottom of the lake is ten feet below sea level, which demonstrates its recent submergence. Its access to the ocean was cut off by sand dunes which dammed up its channel till the water stood ten feet above tide.

The contrast between the ocean shore-line and that of the bay is noted. The former presents steep cliffs and sandy beaches due to the vigorous action of the waves, while the latter has a tidal marsh, in places some miles wide. This marsh may be due to the deposition of material from the bay water during the rainy season. The fact that the tidal marsh is perfectly level and the tidal streams reach back to its rear, indicates that there has been no very recent uplift. On the other hand there may have been a slow subsidence, during which the rate of deposition was equal to the subsidence.

The colored relief map accompanying the paper is worthy of special note for its elegance and effectiveness.

A. H. PURDUE.

ABSTRACTS.

University Geological Survey of Kansas. By ERASMUS HAWORTH AND ASSISTANTS. (Vol. I, 320 pp., pl. XLI. Topeka, 1896.)

This report covers the whole of the Carboniferous of the state and includes notes on various detailed sections across the area, studies of the stratigraphy and lists of characteristic fossils. Economic geologists will be especially interested in chapters XI and XII, relating to the coal and oil and gas fields. In all some twenty counties have produced more or less coal and the output for 1894 was valued at $4,889,774.62. Nearly 90 per cent. of this was won from the Cherokee shales, the basal portion of the Coal Measures. Near the middle of these shales is the heaviest vein occurring in the state. It is known as the Weir City-Pittsburg coal. It outcrops to the southeast and dips northwest at a rate of about 17 feet per mile. It is remarkably uniform in thickness, averaging 40 inches with an occasional maximum of four feet or more. Thinner veins occur both in the Cherokee and other shale beds. The heating power of a number of Kansas coals as determined by Professor Blake of the State University ranges from 9.90 pounds of water evaporated per pound of coal, to 14.43; most of the coals evaporating from 12 to 13 pounds. In volatile matter Professor Bailey, also of the University, finds a range of from 35.32 to 46.14. The water ranges from 1.31 to 13.70 with the larger number of analyses below 7 per cent. The fixed carbon runs from 28.52 to 54.17 and the ash from 7.46 to 13.96.

Dr. Haworth thinks there are good reasons for believing that coal mining in Kansas will increase with comparative rapidity during coming years, and that the amount of coal present has been very greatly underestimated.

Gas and oil have been suspected to occur in the state since its first settlement, and from time to time wells of more or less volume have been opened up, till in 1890 a dozen towns and cities were principally or wholly supplied with light and fuel from these sources. The major development of the field has been in the last six years and has been brought about largely by the systematic prospecting carried on by the large eastern companies. At present gas is used wholly or partially in

Wyandotte, Paola, Ossawatomie, Fulton, Iola, Humboldt, Cherryville, Neodesha, Independence and Coffeyville, and has been obtained in more limited quantities at Fort Scott, Girard, Pittsburg and elsewhere. Oil is obtained in considerable quantities at Peru, Neodesha, Thayer, Independence, Ossawatomie and elsewhere. Quite flattering results were being obtained by prospectors in the early months of the present year when the report went to press. The field, as now outlined, includes 8500 square miles and is approximately bounded as follows: From Kansas City draw a line to Lawrence and from the latter point continue it through to Sedan in Chautauqua county. With the exception of about 500 square miles in the southeast, the area included is all within the field; not a single county within these limits having failed to produce oil or gas or both. Nine-tenths of the flow has come from the sandstones found in the Cherokee shales, though each of the shale beds from the Mississippian to the Lane shales has proven more or less productive. The flows are not exceptionally heavy, though there are strong wells at Neodesha and the Palmer well at Iola yields seven million cubic feet of gas per day. But few paying wells are known which are more than 900 feet deep and many good wells are less than 600. The details of the anticlinals and synclinals present in the field are too imperfectly known to allow any general conclusions as to their influence to be drawn. The Paola well is in one of the greatest synclinals present in the state. In general, structure seems to have had but slight influence upon the collection of the gas, texture being far more potent. The gas and oil are of organic and probably vegetable origin. They are derived from the bituminous shales and collected in the more porous intercalated sand beds. Probably this accounts for the fact that they are more uniformly disseminated in the Kansas field than in any other yet developed in America. Dr. Haworth thinks there is good reason for hoping that the oil and gas industry of the state will ultimately assume considerable proportions even compared with the same industry in the eastern states.

H. F. B.

Till frågan om lommalerans ålder (Concerning the Age of the Lomma clay). Af GERARD DE GEER. Sveriges geologiska undersökning, Afhandlingar och uppsatser, no. 155; Stockholm, 1895.

The author replies to the arguments put forth by Holst and Moberg against evidence for interglacial deposits in Sweden. He calls atten-

tion to the fact that he has not regarded the reference of the Lomma clay to the interglacial river clay (hvitâlera) as being certain and beyond dispute. While his reserve in this respect has been correctly stated by other authors, it has not been indicated by Holst and Moberg. As to the argument made by these gentlemen that a later glacier would have left a heavier moraine resting on the Lomma clay, it is urged that no such moraines have been left by the ice in a great many other places, where the bed-rock is now in view, nor are such moraines now found over extensive areas in Germany and Denmark, where they are known to have been removed by erosion. The undisturbed bedding of the Lomma clay does not preclude the possibility of later glaciers overriding it, for underlying soft beds are not always disturbed under such conditions. As to the fossils which have been found in this clay (*gadus polaris*, *coscinodiscus*, and a number of foraminifera) the author shows that there is reason to believe that the foraminifera have been washed out from the subjacent moraine, and hence may belong to an earlier period. Hence these fossils do not indicate anything with certainty as to the climate obtaining when the clay was deposited. The age of the Lomma clay must still be left an open question. The author does not regard this circumstance as having any important bearing on the hypothesis of a multiple glacial age as applied to Swedish territory. He inclines to the view that the Lomma clay and the Yoldia clay both belong to a horizon between the drift of the earlier glaciation and the drift of the Baltic ice-sheet, but he leaves the question unsettled as to the climatic conditions indicated by biotic evidence. To distinguish such undetermined deposits as these from other beds which are with certainty known to be interglacial, the author applies to the former the name *intra*glacial.

J. A. U.

Om strandliniens förskjutning vid våra insjöar. (On the Displacement of the Shoreline of our Inland Lakes.) By GERARD DE GEER, Sveriges geologiska undersökning, Afhandlingar och uppsatser; no. 141, pp. 15.

As regards the displacement of the shoreline, the author divides the lakes of the glaciated country about the Baltic Sea into two classes: one including such lakes as have their outlets in the direction of least elevation, and the other including such as have their outlets in the direction of greatest elevation. Nearly all of the lakes in the high-

land of Småland belong to the former class and attention is called to the fact that extensive deposits of clays and marls occur skirting the north shores of these lakes. This indicates that the basins have been tilted to the south. The old lake bottoms have been raised above the water, on the north, and the lakes have been partially emptied. Deposits of sand, now covered by peat, north of the lakes Bolmen and Vidöstern indicate that these lakes have been reduced to about one-half of their original size by this process. It is believed that these lakes lie outside of the latest glacial limits, and the calcareous nature of the clays indicates that these are sediments brought down by glacial streams. The deltas of Klarelfven and Glommen, running into the raised ends of lakes Venern and Öieren, rise above the present level of the water in these lakes. The tilting of Lake Venern from north to south is believed to have been about 13^{m}.

Among the lakes which have been tilted away from their outlets, Stora Le and Vettern are mentioned. Stora Le is about fifty times as long as it is wide and its axis lies in the direction of the gradient of the differential elevation of the region. It appears that since the time this lake was separated from the sea by the barrier over which its outlet now runs, the north end of its basin has been elevated 101^{m}, while the south end has been raised only 92^{m}. Marked cliffs of erosion, submerged deltas, and lagoons indicate a relative sinking of the south end of the basin. It is likely that the displacement of the water level at this place amounts to 9^{m}. From like evidence it appears that the surface of the water in the south end of Lake Vettern has risen 10^{m} since the time this lake was united with the sea.

The last part of the paper touches on the evidences of displacement of the basin of the Ancylus Lake, a great body of fresh water which at one time occupied the basin of the Baltic Sea. The presence of arctic land plants in deposits on the shores of Kattegat renders it probable that this channel was closed at the time an arctic climate yet prevailed. The outlet of the Ancylus lake at that time was most likely over the depressions near Karlsberg or Örebro, north of Lake Vettern. In the south part of the Baltic basin submarine peat bogs show that part of this country has at one time had an elevation of 30^{m} above its present altitude. By a lifting of the north end of the Ancylus basin, the water was displaced to the south, until it made its escape through Öresund. When this lake reached its widest extent, it probably covered an area of $570{,}000^{km}$, exceeding in size all known

bodies of fresh water. Our present knowledge of the changes in level in the Baltic region is very incomplete, and the author urges the importance of more observations bearing on the subject. He is of the opinion that a close study of the changes in the shorelines of many other lakes will give important results in this direction. J. A. U.

The Search for the North Pole. By EVELYN BRIGGS BALDWIN. Published by the author, Chicago, Ill.

The author was meteorologist to the second Peary expedition and spent the year 1893–4 in northern Greenland. The severe conditions that limited the success of that expedition did not quench Mr. Baldwin's ardor for Arctic work, and this book has been prepared as an expression of that interest and as an aid to the necessary means for further enterprises. Its purpose is to awaken a wider interest in northern exploration, to remove erroneous impressions popularly entertained respecting it, and, if haply it may so be, to evoke aid for its continued prosecution.

The attempt of the book is to give a summary history of all Arctic expeditions. It is not confined to those whose chief object was to reach the pole. In this respect the book is broader than its title. The selection of matter has been made with a view to popular interest, and it is to be judged on that basis. It makes no pretension to a discussion of the scientific problems of the north, although matters of scientific interest are woven into the narrative so far as thought consistent with its popular interest. In the choice of extracts from the various narratives there has been only a limited yielding to the allurements of florid coloration, exaggerated heroism and morbid sensationalism which characterize so much of Arctic literature. It is a plain, straightforward, very readable story of a series of remarkable enterprises. It is probably the most complete compilation, within like limits, that has yet been made. T. C. C.

Iowa Geological Survey, Vol. V, Annual Report, 1895, 452 pp., 14 plates, 7 maps. Des Moines, 1896.

In the report upon Jones county Professor Calvin divides the Niagara series into the Delaware, Le Claire, Anamosa and Bertram stages. Of these the Le Claire is of considerable interest in that the

limestones composing it stand at a high angle, not as a result of folding but because of the conditions of deposition which seem to have been much the same as lead to cross-bedding in sandstones. Below the Le Claire is the reef rock of the Delaware, while above are the fine-grained building stones of the Anamosa. The drift deposits of the county include the Kansan and Iowan drift sheets, certain water-laid interglacial beds, the loess and the alluvium. Jones county is near the drift border and the puzzling anomalies of topography characteristic of that region are well developed.

In Boone county Dr. Beyer treats a region lying wholly within the Coal Measures and wholly within the area covered by the Wisconsin drift. The newness of the topography, which has been developed in post-Wisconsin time is striking. The Des Moines river runs through a deep narrow trench which follows the crest of a preglacial ridge. The appearance of the Gary moraine is well shown in Plate IV and the area covered by it is indicated on the map of the superficial deposits of the county which is the first drift map published by the Iowa Survey.

Warren county also is underlain entirely by the Coal Measures. In several detailed sections across the county Professor J. L. Tilton has illustrated their lithological character and structure. They are covered by the Kansan drift, which is in turn mantled by the loess-silt of southern Iowa. The main rivers of the county are considered to be of preglacial age. North Middle and South rivers are thought to have originally flowed southwest into the Cretaceous sea. They were reversed by the post-Cretaceous earth movements and now drain into the Des Moines, a subsequent stream developed along the strike of soft strata.

In Woodbury county there are exposures of the Cretaceous, including the Dakota and Colorado, certain sand beds called the Riverside sands and which, while of uncertain age, are considered to represent the "latest Pliocene or earliest Pleistocene," the Kansan drift, the loess and the alluvium. The Cretaceous beds have an important historical interest, and the loess is of great thickness and quite characteristically developed. Certain interloessial beds of drift are interpreted as the result of berg ice and considered as indicative of a close relationship between the loess and the Wisconsin ice; a relationship which later studies in adjacent regions do not seem to confirm.

The studies in Washington county are a continuation of those

carried on in Mahaska and Keokuk counties and reported upon in Volume IV. The Coal Measure areas are more limited, the areal development of the Augusta is greater, and the Kinderhook comes in. The latter is described as being made up of the Wassonville limestone, English River gritstone and Maple Mill shale, of which the latter may possibly be at once the upper continuation of the Devonian and the downward extension of the Carboniferous. The close relationship between the two systems is emphasized. The Pleistocene beds include the Kansan drift, loess-silt and the alluvium. The Iowan does not extend into the county and the loess-silt is an extension of the fossiliferous loess of the Iowan drift border.

Appanoose county is of interest in that the Coal Measures show an unusually regular phase of development. The Appanoose beds, as they have been called, include limestone, shales and a coal seam, which maintain their thickness and general character throughout an area of about 1500 square miles in Iowa and Missouri. The conditions of deposition were remarkably uniform and indicate a considerable change from the turbulent and rapidly varying conditions usual in the Des Moines terrane. It has been possible in this county to accurately map the coal-bearing area and a section from Ottumwa southwest indicates the probable presence of lower coal beds, a fact of considerable economic import. The Pleistocene problems are much the same as in Warren and Washington counties and the beds present are the continuations of those described in those counties.

H. F. B.

Monoclinic Pyroxenes of New York State. HEINRICH RIES. (Cont. Min. Dept. Columbia Univ., Vol. VI, No. 6; Annals New York Acad. Sci., Vol. IX, pp. 124–178, pls. XIII–XVI. New York, 1896.)

The pyroxenes of New York occur in the following conditions: (1) as primary constituents of igneous rocks; (2) along the contact zones between the limestones and intrusive rocks; (3) in crystalline limestones in areas of regional metamorphism; (4) associated with iron ore bodies. The present paper includes results of crystallographic, chemical and optical investigations of all the monoclinic pyroxenes of the state, with the exception of Wollastonite. The crystallographic forms found to occur are few in number, but the combinations and the relative development of the faces are in most instances quite character-

istic of the locality. These peculiarities are mentioned under the detailed descriptions of the different localities which follow the more general portion of the paper. Mr. Ries' investigation of the relation between the optical and chemical properties of the pyroxenes, shows that the extinction angle does not increase with the percentage of FeO, thus disagreeing with Wiik's results, although the latter himself found several exceptions to his rule. Comparing the extinction angle with the corresponding sums of the ferrous and ferric iron gives no better results. If, however, the combined percentages of FeO, Fe_2O_3 and Al_2O_3 be taken, a more regular series is obtained. If, furthermore, those containing less than 3 per cent. of Al_2O_3 be excluded from the list as more properly belonging to Diopside, a still better series is obtained, though not even then is the series a perfectly regular one. The results of etching agree very closely with those obtained by Wulfing and by Greim. In the chemical investigation Mr. Ries has attempted to calculate in each case the mixture of metasilicates. His analyses indicate that Tschermak's theory of the relation between Al_2O_3 and the oxides of Ca, Mg, and Fe holds good in the case of only about one-half of the New York pyroxenes analyzed. Not the least valuable portion of the paper is a list of the literature bearing on the subject and including some sixty papers. H. F. B.

Fifteenth Annual Report of the United States Geological Survey, 1893–4.

The administrative portion of the report is followed by five papers of considerable importance. The first is a preliminary report upon the Geology of the Common Roads of the United States, by N. S. Shaler, and includes an outline of the history of American road building, with studies on the value and distribution of road stones, the methods of their use, the effects of geologic structure on the grade of roads, the value of block paving and paving brick and the action of rain and frost upon roads and road material. The paper is a timely contribution to a subject of increasing interest.

The second paper is by L. F. Ward and is upon the Potomac formation. It is the result of detailed studies upon the flora and the stratigraphy of the formation. It is notable in that Mr. Ward divides the formation into six separate series of beds to which local names are given.

A. C. Lawson contributes a sketch of the Geology of the San

Francisco Peninsula, which includes studies of the Franciscan series, the Serpentine, the Tejon sandstone, the Merced series, the Terrace formations and the diastrophic record.

The Marquette iron-bearing district of Michigan is treated in a preliminary report by Van Hise and Bayley, with a chapter upon the Republic trough by H. L. Smyth. The Basement Complex, the Lower Marquette and the Clarksburg formations are treated with considerable detail.

The Origin and Relations of the Central Maryland Granites is treated by C. R. Keyes after an important introductory chapter upon the General Relations of the Granite Rocks in the Middle Atlantic Piedmont Plateau, by the late Professor G. H. Williams.

H. F. B.

Notes Concerning a Peculiarly Marked Sedimentary Rock. By DR. J. E. TALMAGE, President and Deseret Professor of Geology, University of Utah. Published in pamphlet form, with five plates, reprinted from the *Utah University Quarterly*.

The author describes and illustrates a fine-grained argillaceous sandstone, bearing peculiar surface markings consisting mostly of straight lines intersecting at right angles with almost mathematical precision. The deposit was examined by the writer in place, and an extensive collection of specimens was made under his direction by the "Utah University and Deseret Museum Expedition of 1895." The formation consists of undisturbed sedimentary deposit, referred to Trias or Jura-Trias age, and occupies a relatively low table land between the Kaiparowitz and the Paria plateaus on the north of the Colorado River near Glen Canyon, Arizona. The bed of marked rock is almost two feet thick, and lies conformably between deposits of coarser sandstone, which show none of the rectilinear markings. While the most regular arrangement of the marks appears on slabs with perfectly flat surfaces, yet the rectilinear intersections are plainly shown on warped and ripple-marked surfaces. The lines are so regular as to suggest the possibility of human instrumentality when hand specimens only are examined. The author has performed a number of experiments to test the theory of sun-crack or shrinkage-fissure origin, with negative results; but succeeded in producing marks similar in appearance through the formation of ice-crystals on mud formed from the pulverized stone. Then by pouring on such mud concentrated natural brine from the

Salt Lake, crystals of mirabilite and others of common salt were formed, and these impressed the mud, producing straight lines though without rectilinear intersections. The writer says with reference to this last experiment:

"One would hardly hold, even as a working hypothesis, that lines of 200 or 500 cm. could be produced in any such way; though the supposition may be ventured that under particularly favorable conditions a thin crystalline cake might form on shore sediments, and this by a cleavage of its own might become fissured in an orderly way, the cracks extending to the mud surface beneath, and marking the same superficially; or if the under stratum had a very thin top layer of fine-grained material the depressions might extend through the same. A fresh addition of sediment would fill the cracks and perpetuate the mud marks, while the deposit of soluble mineral might be removed by solution. Shallow line-like depressions in the mud might possibly determine the position of incipient cracks in a subsequent process of slow shrinkage. However, such suppositions lack a stable experimental foundation."

RECENT PUBLICATIONS.

—BATHER, F. A., Uintacrinus, a Morphological Study.—Proc. Zoöl. Soc. London, 1895, pp. 974–1004, pls. LIV–LVI, London, 1896.

—BEYER, S. W., Sioux Quartzite and Certain Associated Rocks.—Iowa Geol. Surv., VI, 67–112, Des Moines, 1896.

—BOUE, MARCELLIN, La Topographie Glaciaire en Auvergne.—Ann. de Géog, 5th Ann., No. 21, pp. 277–296, pl. VII, Paris, 1896.

—CLARKE, HENRY L., The Life History of Star Systems.—Popular Astronomy, No. 30, 31 pp., pls. XVIII–XXII.

—CLENDENNIN, W. W., Preliminary Report upon the Florida Parishes of East Louisiana and the Bluff, Prairie and Hill Lands of Southwest Louisiana.—Made under the direction of State Experiment Stations, pp. 159–256, Baton Rouge, 1896.

—Committee Report of the Research Committee Appointed to Collect Evidence as to Glacial Action in Australia.—Australasian As. Adv. Sci., 6 pp., pls. XLIX–L, Brisbane, 1895.

—DAVID, T. W. E., Geology and Mineralogy.—Australasian As. Adv. Sci., 41 pp., pls. I–II, Brisbane, 1895.

—DAVID, T. W. E., W. F. SMEETH and J. A. SCHOFIELD, Notes on Antarctic Rocks Collected by Mr. C. E. Borchgrevink.—Royal Soc. N. S. Wales, 32 pp., 3 pls., Dec. 1895.

—Dept. of Agriculture, Rept. Fourth Annual Meeting Amer. As. State Weather Services.—U. S. Dept. Agri., Weather Bureau, Bul. 18, 55 pp., Washington, 1896.

—FROSTERUS, BENJ., Ueber einen neuen Kugelgranit von Kangasniemi in Finland.—Bul. de la Comm. Géol. de la Finland, 38 pp., 2 pls., Helsingfors, 1896.

—GEIKIE, ARCHIBALD, Tertiary Basalt-Plateaux of Northwestern Europe.—Quart. Jour. Geol. Soc., Vol. III, pp. 331–406, pls. XV–XIX, London, 1896.

—HAGUE, ARNOLD, Age of the Igneous Rocks of the Yellowstone National Park.—Amer. Jour. Sci., (4), I, 445–457, New Haven, June 1896.

—HALL, C. W., The University of Minnesota; a Historical Sketch.—75 pp., Minneapolis, 1896.

—KEYES, CHARLES R., An Epoch in American Science.—Annals of Iowa, (3), II, 345–364, Des Moines, 1896.

—KEYES, CHARLES R., Missouri Building and Ornamental Stone.—Stone, XII–XIII (reprint), 20 pp., Chicago, 1896.

—KEYES, CHARLES R., North American Fossil Crinoidea Camerata.—Jour. Geol., IV, II, 221–239, Chicago, 1896.

—LEONARD, A. G., Lead and Zinc Deposits of Iowa.—Iowa Geological Survey, VI, 10–66, Des Moines, 1896.

—MARSH, O. C., A new Belodont Reptile (Stegomus) from the Connecticut River Sandstone.—Amer. Jour. Sci., (4), II, 59–62, 1 pl., New Haven, 1896.

—RICHTER, E., Beobachtungen über Gletscherschwankungen in Norwegen, 1895.—Abdruck aus Dr. A. Petermann Mitt., 1896, Heft 5, pp. 107–110.

—RICHTER, E., Die Gletscher Norwegens.—Geog. Zeit., herg. von A. Hettner, II Jahr., pp. 305–319, 1896.

—RICHTER, E., Die Norwegische Strandebene und ihre Entstehung.—Globus, Bd. LXIX, Nr. 20, 6 pp.

—RICHTER, E., Geomorphische Beobachtungen aus Norwegen.—Sitzungsber. d. K. Akad. Wiss., Wien, Math-nat. Classe, Bd. CV, Abth. I, 43 pp., 2 pls., 1896.

—RIES, HEINRICH, The Monoclinic Pyroxenes of New York State.—Cont. Mineral Dept. Columbia Univ., IV, VI, 124–178, pls. XIII–XVI, New York, 1896.

—Transactions Kansas Acad. Sci., XIV, 370 pp., Topeka, 1896.—Containing: A Dying River, J. R. Mead; The Topeka Coal Hole, B. B. Smyth; Coal in Atchison county, Kansas, E. B. Knerr; Rock Exposures about Atchison, John M. Price; The Terminal Bowlder Belt in Shawnee County, B. B. Smyth; On the Eastern Extension of the Cretaceous Rocks in Kansas and the Formation of Certain Sand Hills,

Robert Hay; The River Counties of Kansas, Robert Hay; A Bibliography of Kansas Geology, Robert Hay.

—TURNER, H. W., Notice of some Syenitic Rocks from California.—Amer. Geol., XVII, 375–388, Minneapolis, 1896.

—U. S. Geological Survey:

—CLARKE, F. W., The Constitution of the Silicates.—Bul. U. S. Geol. Surv., No. 125, 109 pp., Washington, 1895.

—EMERSON, B. K., A Mineralogical Lexicon of Franklin, Hampshire and Hampden counties, Massachusetts.—Bul. U. S. Geol. Surv., No. 126, 180 pp., 1 pl., Washington, 1896.

—GANNETT, HENRY, A Dictionary of Geographic Positions in the United States.—Bul. U. S. Geol. Surv., No. 123, 183 pp., 1 pl., Washington, 1895.

—NEWELL, FREDERICK HAYNES, Report of Progress of the Division of Hydrography for the Calendar Years 1893 and 1894.—Bul. U. S. Geol. Surv., No. 131, 126 pp., Washington, 1895.

—PERRINE, CHARLES D., Earthquakes in California in 1894.—Bul. U. S. Geol. Surv., No. 129, 25 pp., Washington, 1895.

—POWELL, J. W. (Director), Fifteenth Annual Report of the U. S. Geol. Surv., 1893–4, XIV, 755 pp., 48 pls., Washington, 1895.

—SCUDDER, SAMUEL HUBBARD, Revision of the American Fossil Cockroaches, with Descriptions of New Forms.—Bul. U. S. Geol. Surv., No. 124, 176 pp., 12 pls., Washington, 1895.

—STANTON, TIMOTHY W., Contributions to the Cretaceous Palæontology of the Pacific Coast.—Bul. U. S. Geol. Surv., No. 133, 130 pp., 20 pls., Washington, 1895.

—WALCOTT, C. D. (Director), Sixteenth Annual Report of the U. S. Geol. Surv.: Part ii, Papers of an Economic Character; Part iii, Mineral Resources, 1894, Metallic Products; Part iv, Mineral Resources, 1894, Non-metallic Products.

—WALCOTT, CHARLES D., The Cambrian Rocks of Pennsylvania.—Bul. U. S. Geol Surv., No. 134, 43 pp., 15 pls., Washington, 1896.

—WHITE, CHARLES A., The Bear River Formation and its Characteristic Fauna.—Bul. U. S. Geol. Surv., No. 128, 108 pp., Washington, 1895.

—WINSLOW, ARTHUR, The Disseminated Lead Ores of Southeastern Missouri.—Bul. U. S. Geol. Surv., No. 132, 31 pp., 6 pls., Washington, 1896.

—WARD, LESTER F., Fossil Plants of the Wealden.—Science, June 12, 1896, 869–876.

—WHITNEY, MILTON, Reasons for Cultivating the Soil (Reprint).—Yearbook U. S. Dept. Agriculture, 1895, pp. 123–130.